SECTION 4. LAND USE

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SECTION 4. LAND USE

4.1 Introduction to the Phase 5.3 Model Land Use

Creating a quality land use data set to meet the needs of the Phase 5.3 Model was a challenging element of the Phase 5.3 development. Phase 5.3 required a consistent land cover data set for the entire Phase 5.3 Model domain, an area of eight states including Maryland, Delaware, and Virginia, in their entirety. Further, the land use estimates needed to change annually over the 1985 to 2005 simulation period. Compounding the difficulty was the need to have corresponding data sets of estimated manure and fertilizer inputs for agricultural and developed lands. The best available data sets providing a consistent level of accuracy throughout the Phase 5.3 domain were integrated to produce a final Phase 5.3 Model land use data set, with an emphasis on accuracy in the developed and agricultural areas. Developed lands encompass the majority of dense urban areas and some suburban and rural development.

The Phase 5.3 Model expands land uses to 26 types, including 11 types of cropland, 2 types of woodland, 3 types of pasture, 5 types of developed land, water surfaces of rivers and lakes, and provisions for other special land uses such as surface mines, animal feeding operations and combined sewer systems. Land uses are divided into two principle types, pervious and impervious. The nutrients in the major pervious land uses of woodland, cropland, hay, pasture, and developed pervious are simulated using the AGCHEM modules within HSPF (Bicknell et al. 2001) that fully simulate forest or crop nutrient cycling, including uptake by plants. The minor pervious land uses, which are harvested forest, land under construction, nurseries, surface mines, and degraded riparian pasture, are simulated through HSPF's PQUAL (Bicknell et al. 1997; 2001; Donigian et al. 1984; Johanson et al. 1980) which represents nutrient export through concentration coefficients. Impervious land uses are simulated through the HSPF IQUAL modules (Bicknell et al. 1997), which use accumulation and washoff coefficients to simulate nutrient and sediment export. Each AGCHEM land use is simulated on an hourly time step tracing the fate and transport of input nutrient loads from atmospheric deposition, fertilizers, animal manure, legume fixed nitrogen, and point sources.

All land uses are simulated as a single average unit area, or a single acre, in each segment, and that single acre is then multiplied by the acres of each land use draining to each river-segment. The final Phase 5.3 land use is available as a sub-county tabular database for the years 1982, 1987, 1990, 1992, 1997, 2000, 2002 and is available for every year in the 1985 to 2005 simulation period by further interpolation. The annual Phase 5.3 sub-county tabular data sets of land use are available in the Phase 5.3 Model Data Library at http://ches.communitymodeling.org/models/CBPhase5/datalibrary.php or http://www.chesapeakebay.net/phase5.htm.

4.2 Developing Phase 5.3 Land Cover Data

Land cover for the Chesapeake Bay watershed portion of the Phase 5.3 domain (Zone 1)[1] was developed differently from those south of the Chesapeake watershed (Figure 4-1, Zones 2 and 3).

[1] A more detailed description of Phase 5.3 data zones is provided in Section 4.2.10.

Sections 4.2.1 through 4.2.9 below discuss the development of Phase 5.3 land cover in Zone 1, and Section 4.2.10 describes Phase 5.3 land cover development for Zones 2 and 3.

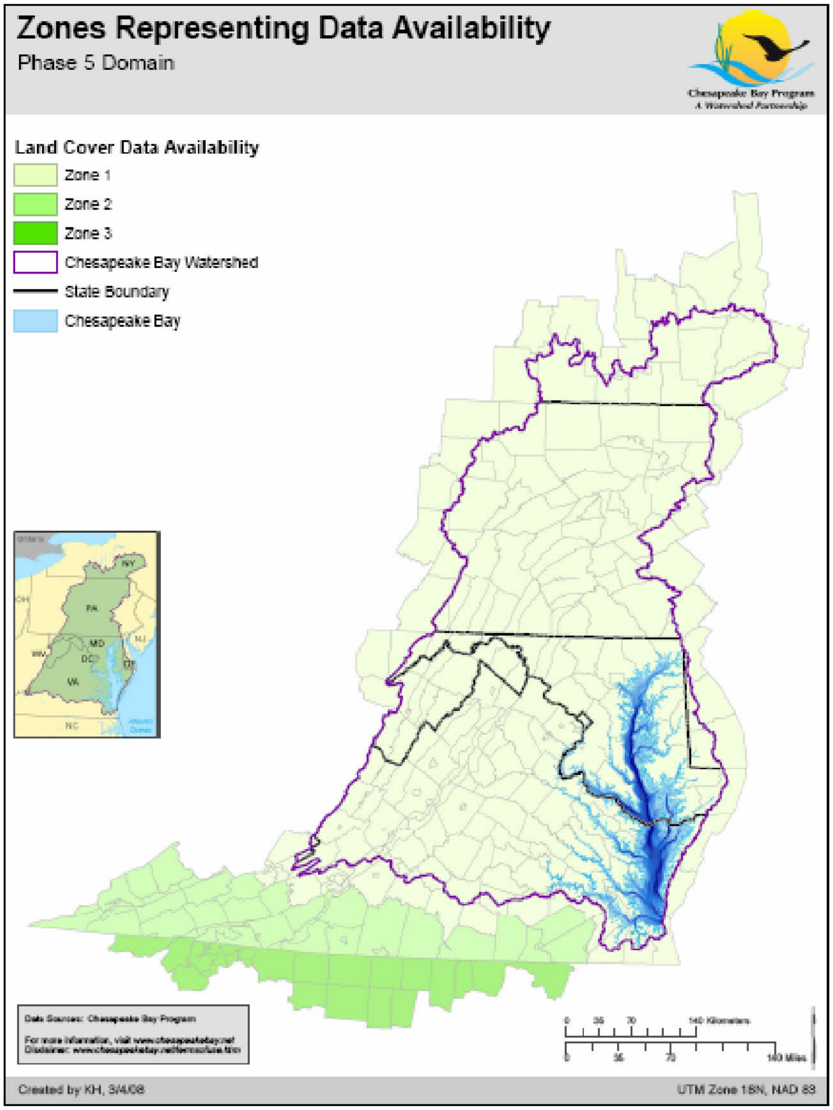


Figure 4-1. Data zones in the Phase 5.3 domain where different land cover data approaches were used.

4.2.1 Chesapeake Watershed Land Cover Data Series

The Chesapeake Bay Land Cover Data series (CBLCD) covering Zone 1 was designed to provide a 1985 to 2005 annual time series of land cover data consistent across the watershed and intersecting counties. The data are based on a series of four 30-meter resolution Anderson Level-2 (Anderson et al. 1976) raster land cover data sets for 1984, 1992, 2001, and 2006 consisting of 16 Anderson Level II land cover classes (Table 4-1) (Irani and Claggett 2010).

Table 4-1. Anderson Level II land cover classes used in the Chesapeake watershed.

Code	Class name	Abbreviation
11	Open Water	OW
21	Developed Open Space	DOS
22	Low Intensity Developed	LID
23	Moderate Intensity Developed	MID
24	High Intensity Developed	HID
31	Barren	BN
32	Unconsolidated Shore	US
41	Deciduous Forest	DF

Code	Class name	Abbreviation
42	Evergreen Forest	EF
43	Mixed Forest	MF
52	Shrub Scrub	SS
71	Grassland/Herbaceous	GH
81	Pasture/Hay	PH
82	Cultivated Crops	CC
90	Woody Wetlands	WW
95	Emergent Wetlands	EW

From that initial group of 16 Anderson Level II land cover classes, a more refined set of 12 land cover classes was developed for each land-river segment in the Chesapeake Bay watershed including counties that intersected the watershed and had a portion of their area in the watershed. Nine counties that intersected the watershed had only partial coverage available (Figure 4-2).[2] The 12 more refined land cover classes were an intermediate step in moving to the detail of the 26 Phase 5.3 major land uses. In this document, the 16 CBLCD land cover types will be in initial caps, and actual final Phase 5.3 land uses will be in italics. *Open Water* is the only land cover/land use in both initial caps and italics because that category was a member of both data sets.

Of the 12 land cover classes, only one, the *Open Water* class was tabulated directly from the CBLCD. The remaining classes were created from a combination of CBLCD and ancillary information including the 2001 Impervious Surface Land Cover data developed by the University of Maryland's Regional Earth Science Applications Center (RESAC) (Goetz et al. 2004), and the U.S. Census Bureau *Census of Agriculture*, also called the Agricultural Census, using data on a county level (U.S. Census Bureau 1982, 1987, 1992, 1997, 2002, 2007). Ancillary data from the states were also used to develop an estimate of extractive acreage across the watershed.

4.2.2 CBLCD Base Map

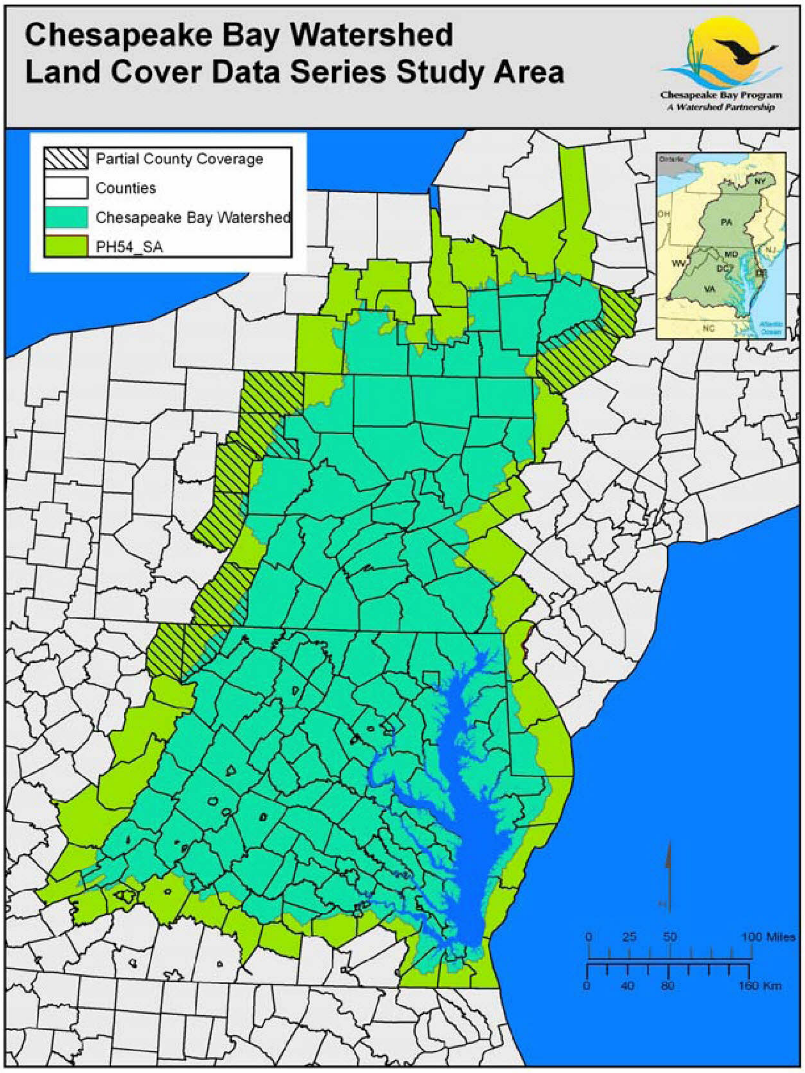
The Chesapeake Bay watershed covers 64,000 square-miles (165,760 square kilometers) and intersects Multi-Resolution Land Characteristics (MRLC) Consortium Mapping Zones 59, 60, 61, 63, and 64 (http://www.mrlc.gov/). The key MRLC land cover product used for Phase 5.3 land use development was the National Land Cover Data (NLCD) (http://www.mrlc.gov/nlcd.php).

[2] Garrett County Maryland; Delaware and Schoharie counties, New York; Elk, Indiana, Jefferson, McKean and Somerset counties, Pennsylvania; and Preston County, West Virginia are only partially covered because acquisition and processing of additional Landsat scenes would be required to fully represent these nine counties.

To provide a starting point from which land cover change could be detected over the 1985 – 2005 period, a 2001 Land Cover Base Map was developed by modifying and merging 2001 USGS NLCD for MRLC mapping zones 59 and 60 with modified NOAA Coastal Change Analysis Program (CCAP) Land Cover Data for MRLC mapping zones 61, 63 and 64 (Figure 4-3).

The CCAP data set was modified by collapsing the six CCAP wetland classes (palustrine forest, palustrine shrub/scrub, palustrine emergent, estuarine forest, estuarine shrub/scrub, and estuarine emergent) into the two NLCD wetland classes (Emergent Wetlands and Woody Wetlands). The NLCD land cover data for Zones 59 and 60 were modified by adjusting Cultivated Crops and Pasture/Hay classes to agree more closely with the extents published in the 2002 Agricultural Census. This was done by including county level proportions of Cultivated Crops and Pasture/Hay derived from the Agricultural Census in a special run of a Classification and Regression Tree (CART) analysis. Other small edits were made by reviewing the spectral analysis of 2001 satellite reflectance data to refine and better match Mixed Forest and Scrub/Shrub classes between the NLCD and CCAP data sets.

The CBLCD-developed classes originated with NLCD and CCAP, which used satellite imagery reflectance to determine percent Impervious Surface Area (ISA) per pixel to differentiate Developed Open Space (0–20 percent ISA), Low Intensity Developed (21–49 percent ISA) , Medium Intensity Developed (50–79 percent ISA), and High Intensity Developed (80–100 percent ISA). The NLCD produced its own impervious surface data set, and the CCAP work used those NLCD-developed land cover classes for 2001 as a starting point.



Note: Diagonally shaded counties are only partially covered by CBLCD land cover data.

Figure 4-2. The CBLCD land cover area.

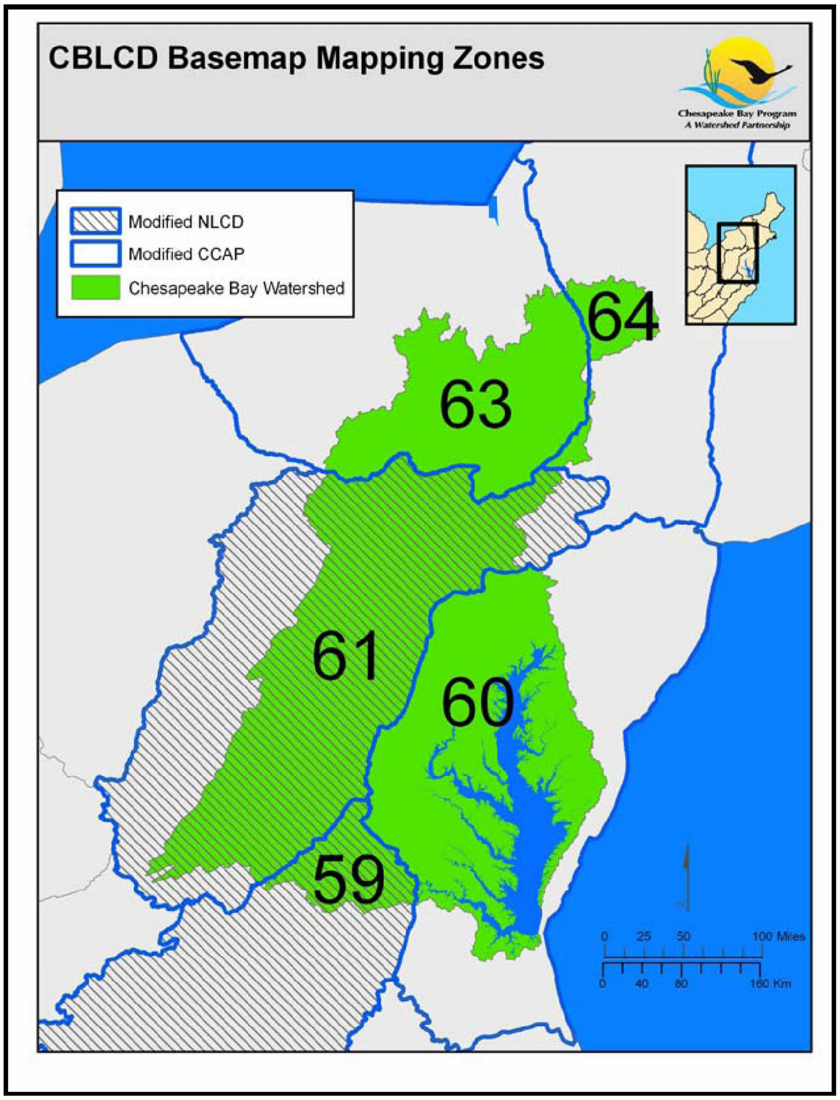


Figure 4-3. CBLCD baseline MRLC mapping zones.

Extensive quality checking and comparisons with moderate- and high-resolution satellite imagery, aerial photography, and other ground truthing were done to finalize the CBLCD 2001 base map. That map and appropriate satellite reflectance data were used to examine change over time between 2001 and 2006 and between 2001 and 1992. Once the 1992 land cover map was created, it was used as a base map to identify change between 1992 and 1984 reflectance data (Figure 4-4).

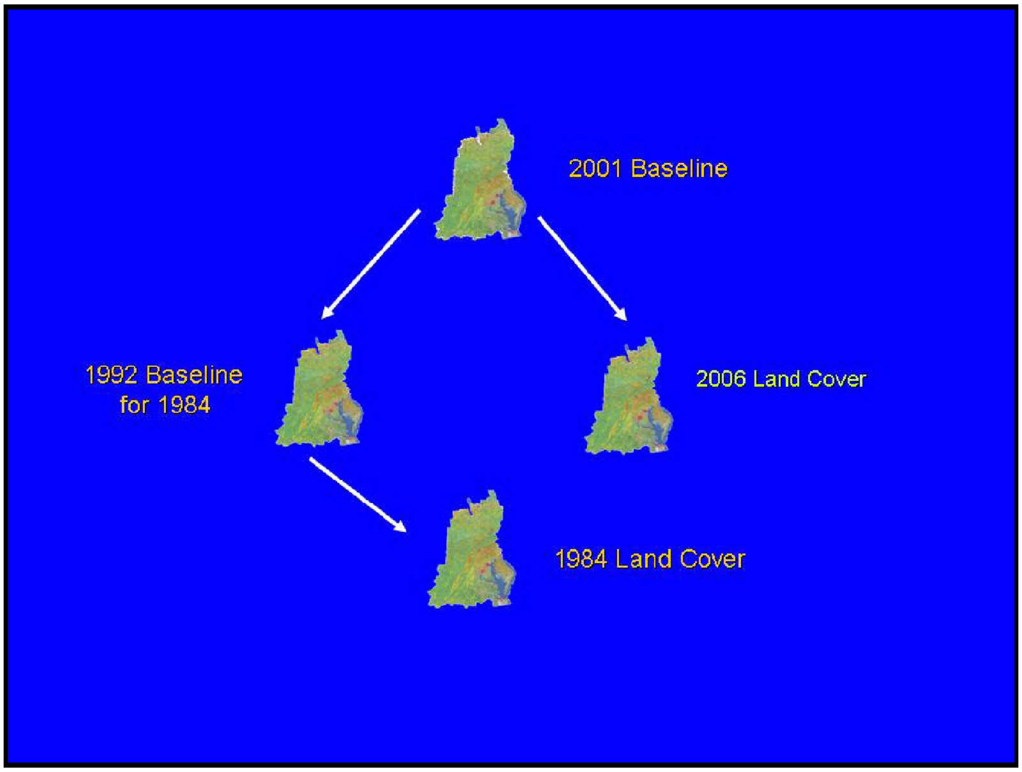


Figure 4-4. The 2001 baseline map is used to create 2006 and 1992 land cover; subsequently, the 1992 map is used to create 1984 land cover.

4.2.3 Land Cover Change Analysis

Changed land cover pixels were identified by the proprietary Cross Correlation Analysis process, http://www.mdafederal.com/environment-gis/remote-sensing/change-detection/?searchterm=cca and the nature of the class-to-class change was determined by CART analysis of changed pixels.

To detect change between the baseline and target-year land cover, the Cross Correlation Analysis computes target year multi-band Landsat satellite reflectance value z-scores for each 2001 land cover class footprint overlaid on the target year reflectance data. Z-scores that differed greatly from the average target year z-score for each 2001 land cover class footprint were labeled *change pixels*, and those pixels were subsequently classified via CART analysis. The classified changed pixels were then overlaid and incorporated into a copy of the original 2001 map to create the target-year land cover map (Figure 4-5).

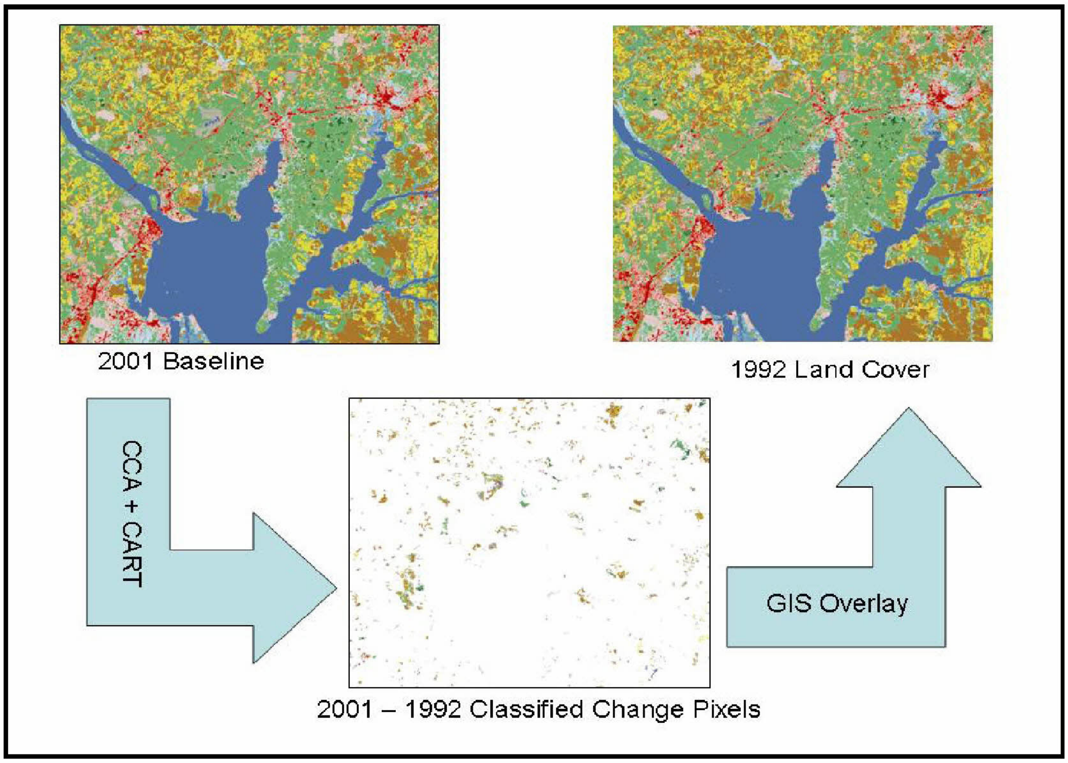


Figure 4-5. CART analysis classifies changed pixels which are then superimposed on the 2001 baseline map to create target year land cover maps.

The NOAA CCAP project (http://www.csc.noaa.gov/digitalcoast/data/ccapregional/) had already completed the Cross Correlation Analysis + CART process for the 2001–2005 years for MRLC Zones 61, 63, and 64. For that reason, it was necessary to process only satellite data to update the base map for Zones 59 and 60 and merge the results with the existing CCAP land cover for 2006 after first collapsing the 2006 CCAP wetland classes to match NLCD classes. The 2006 CBLCD, therefore, represents conditions in 2005 in the Coastal Plain and eastern Piedmont physiographic provinces and 2006 conditions in the Ridge and Valley and Appalachian provinces.

Because CCAP land cover data does not exist for 1992 or 1984, the 1992 CBLCD was created using the change detection techniques described above for the entire Bay watershed and intersecting counties. The 1992 CBLCD was then used as a new baseline to create the 1984 CBLCD. Thus, to create the 1984 data set, change was detected between 1984 and 1992 rather than between 1984 and 2001. Both approaches were tried, but the former proved to be more accurate.

4.2.4 Quality Control

Throughout this process, the USGS and NOAA cooperated to perform a predefined Quality Check (QC) procedure to identify, discover, and document any problems for verification and correction. The QC team created Excel tables specifying a map coordinate and description of detected problems for each of the four land cover data sets. The tables were then updated with a description of how each problem was either corrected or, in some cases, determined not to be a problem. Each year's CBLCD land cover map went through provisional and revised drafts until a final version was accepted by the resolution of all identified QC flags.

4.2.5 Post-Processing

When the USGS and NOAA accepted the final versions of all four dates of land cover data sets (1985, 1992, 2001, and 2006), several post-processing procedures were performed to correct known problems remaining with the data. Those included targeted editing to correct known misclassified areas and executing an algorithm to reclassify narrow linear areas of emergent wetland pixels occurring along the shore of the Bay. Such areas along the shoreline of the Bay are often misclassified as emergent wetlands because of the mixture of water/land reflectance values (Figure 4-5).

4.2.6 CBLCD Conversion to Phase 5.3 Land-Segment Tabular Input

As an initial step in developing the Phase 5.3 Watershed Model land use, estimates were required of acreage per Phase 5.3 land-river segment for 12 land cover classes, which included *Open Water*, *extractive-active and abandoned mines*, *high intensity impervious*, *high intensity pervious*, *low intensity impervious*, *low intensity pervious*, Pasture/Hay, Cultivated Crops, and Agriculture[3,4] (Figure 4-6). Pasture/Hay, Cultivated Crops, and Agriculture were large super categories that were further broken down into finer Phase 5.3 land uses in subsequent steps described in Section 4.3. The 16 2001 CBLCD land cover classes were translated into the 10 Phase 5.3 land covers through a combination of GIS operations and tabulations (Figure 4-7).

To do that, the acreage per land-river segment of the CBLCD classes *Open Water*, Pasture/Hay and Cultivated Crops were directly tabulated without modification. Pasture/Hay and Cultivated Crop acreage were summed to create the total estimated Agriculture area. As described in Section 4.3, to spatially distribute county-level U.S. Census of Agriculture statistics to land-river segments, the proportions of a county's total Pasture/Hay and Cultivated Crops acreages in each land-river segment were multiplied by the extent of crops and pasture in each county as published in the U.S. Census of Agriculture.

The Phase 5.3 land uses of high intensity impervious, high intensity pervious, low intensity impervious, low intensity pervious, and estimates for the extractive-active and abandoned mines, were generated using ancillary information (Figure 4-8).

[3] The areas of partial CBLCD land cover counties that have no CBLCD coverage are planned to be filled with 2000 NLCD land Cover in future CBWM calibration procedures.
[4] Actual land uses used in the Phase 5.3 Watershed Model are in italics throughout this document.

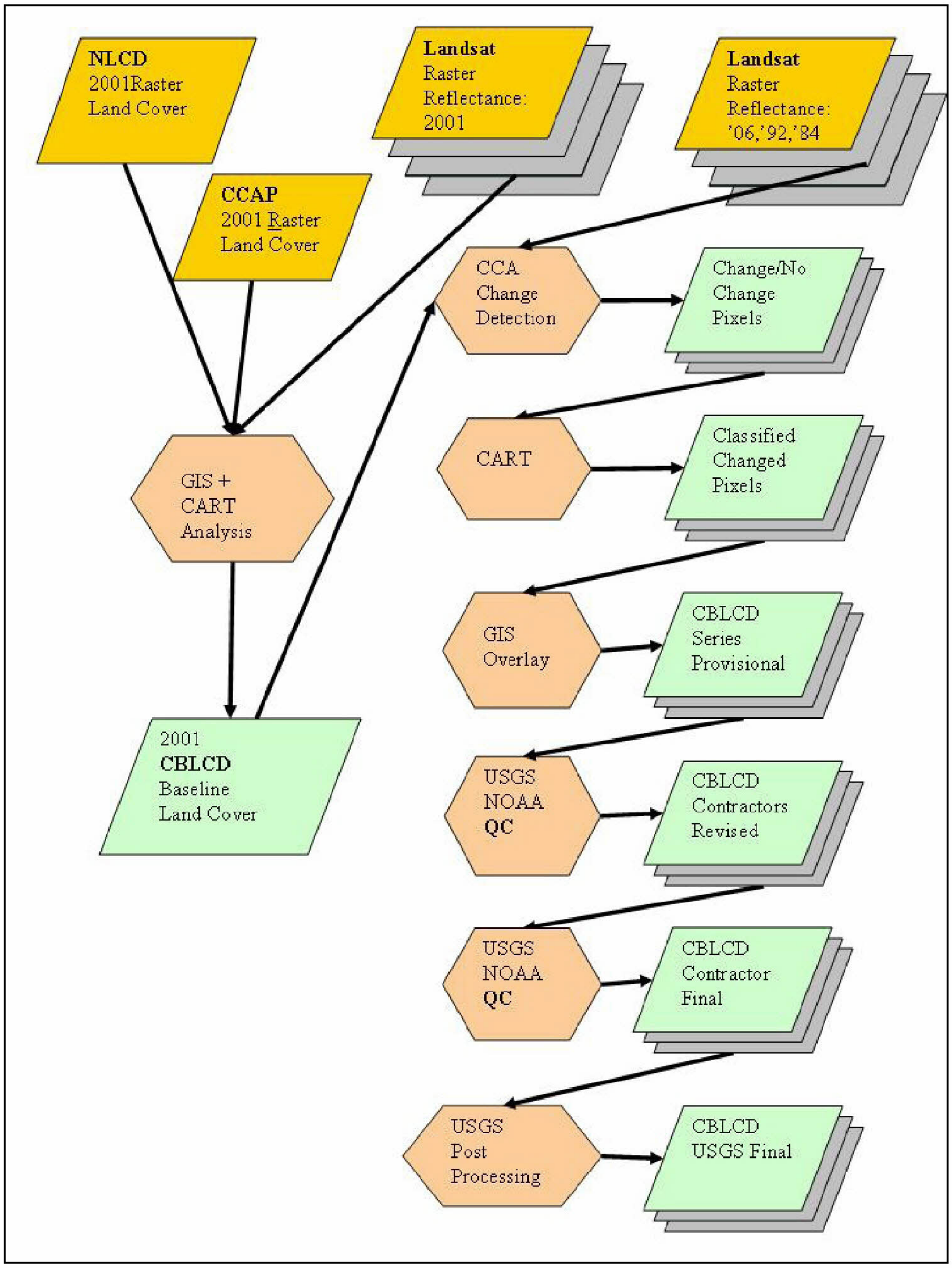


Figure 4-6. General workflow to create the CBLCD 1984–2006 land cover data.

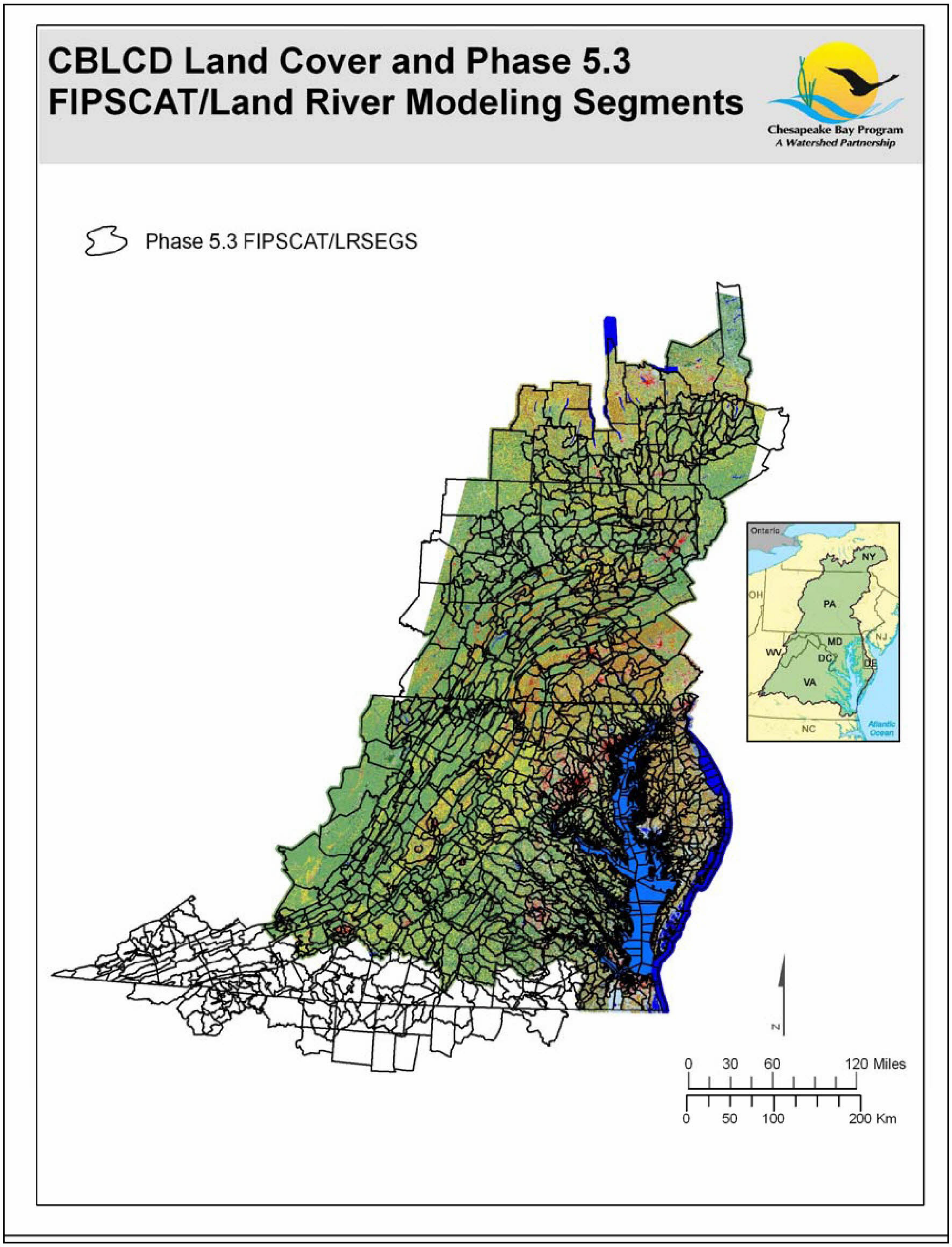


Figure 4-7. Phase 5.3 Watershed Model segments and CBLCD land cover area.

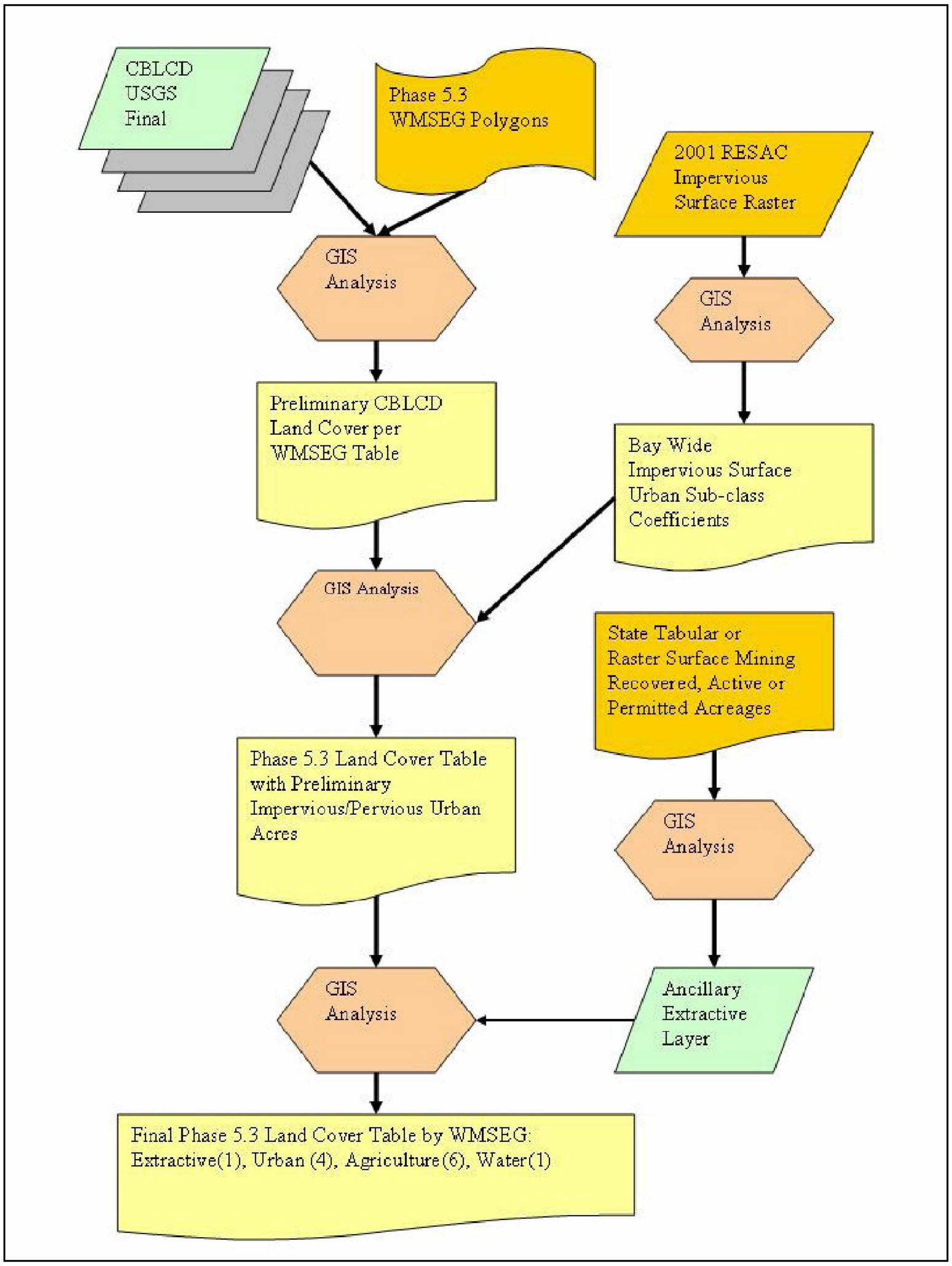


Figure 4-8. Data flow to create Phase 5.3 land cover by land-river segment (WMSEG).

4.2.6 Extractive Data Layer

The CBLCD does not have an *extractive-active and abandoned mines* land use class, which includes quarries and surface mines. To develop that land use, GIS information regarding the type and extent of permitted, restored, and active surface mine acreage were obtained from each state. Only West Virginia and Delaware had spatial polygon information delineating the size and shape of their mining operations. New York, Pennsylvania, Maryland, and Virginia had tabular information of acreages assigned to point locations (Table 4-2).

Table 4-2. Surface mine data sources by state agency.

State	Agency	Data set
Delaware	Office of Management and Budget Geographic Data Committee	2007 Extractive
Maryland	Department of Environment Minerals, Oil and Gas Division	2009 Surface Mines
New York	Department of Environmental Conservation Division of Mineral Resources	GIS Mines to 2009
Pennsylvania	Department of Environmental Protection Division of Environmental Analysis and Support	Reclaimed or Forfeited Mines in PA 9-29-2009
Virginia	Department of Mines, Minerals and Energy	Active Permits
West Virginia	Office of Abandoned Mine Lands and Reclamation (AMLR) of the WVA Dept. of Environmental Protection	WVA Permit Boundaries

4.2.7.1 Approximation of Maryland Active Mine Acres

All six states reported information on permitted acreages of extractive land, and most also reported the area that is active or disturbed. West Virginia provided a polygon data set delineating the acreages of disturbed areas. Delaware provided a land cover map with an extractive layer from which polygons could be extracted and aerial statistics could be derived for each mine. Pennsylvania had an authorized category of mine acres corresponding to portions of permitted acres that were actively being mined. New York and Virginia had permitted and disturbed column entries for permitted mining acres. Maryland provided information for permitted acres, but information on active or disturbed acres was unavailable. Because permitted acres can exceed active acres at a given time, active/disturbed acres for Maryland were approximated using regression coefficients derived from relationships between permitted to disturbed mining acreages reported in the Virginia data set. Virginia's permitted and corresponding disturbed acres for surface mine locations were used to derive regression coefficients. Those coefficients were then applied to Maryland permitted acres to approximate a disturbed acreage value for each surface mine location (Table 4-3 and Figure 4-9).

Table 4-3. Permitted to disturbed area regression coefficients for Virginia.

Regression Statistics		
Multiple R	0.822673066	
R Square	0.676790974	standard error.
Adjusted R Square	0.676299027	
Standard Error	112.448025	
Observations	659	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	17395627.98	17395628	1375.74	2.7719E-163
Residual	657	8307474.827	12644.56		
Total	658	25703102.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.822409469	4.89719441	0.372133	0.709314	-7.793629681	11.43845	-7.79363	11.43845
PERMITTED_	0.472505735	0.012739103	37.09097	2.8E-163	0.447491471	0.49752	0.447491	0.49752

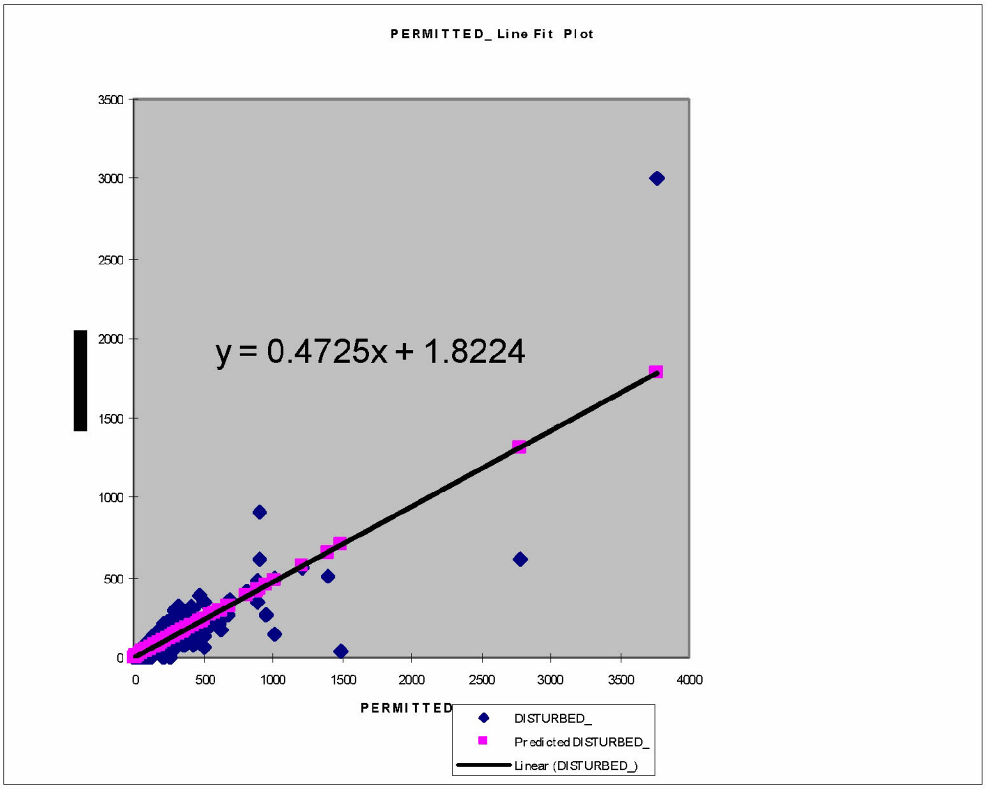


Figure 4-9. Approximation of disturbed acres of extractive area from permitted extractive area.

4.2.7.2 Extractive-Active and Abandoned Mines Mask Creation

Surface mines for states where only point locations were provided were represented as circles proportional to the reported or modeled active acreage at each site. The extractive circles and irregular polygons throughout the watershed were merged to form an extractive data layer or mask. The acreage of *extractive-active and abandoned mines* land use was then tabulated within each land-river segment.

4.2.7.3 Correcting for Confusion Between Developed and Extractive Land Covers

An overlay of the extractive data mask on the 2006 CBLCD showed frequent confusion of the *extractive-active and abandoned mines* class with the Barren and Developed classes (Figure 4-10). The previously tabulated acres of development in each land-river segment, therefore, needed to be reduced by the amount of Developed/Extractive confusion within a land-segment. The amount of barren acres in a land-river segment was first tabulated and subtracted from the extractive acres in the same land-river segment.[5] If the amount of extractive acres exceeded the amount of barren acres in a land-river segment, the lesser value of the remaining extractive acres or the amount of developed acres underneath the extractive mask was subtracted from the total amount of developed acres in the land-river segment. If the amount of barren acres exceeded the

[5] There was no *extractive* class in the 2001NLCD, and much of the 1990 NLCD extractive class was mapped as Barren in the 2001 NLCD. For that and other reasons the Barren acres for all the land-segments was subtracted rather than just barren beneath the ancillary extractive mask.

amount of extractive acres in the land-river segment, no modification to the amount of developed lands was performed.

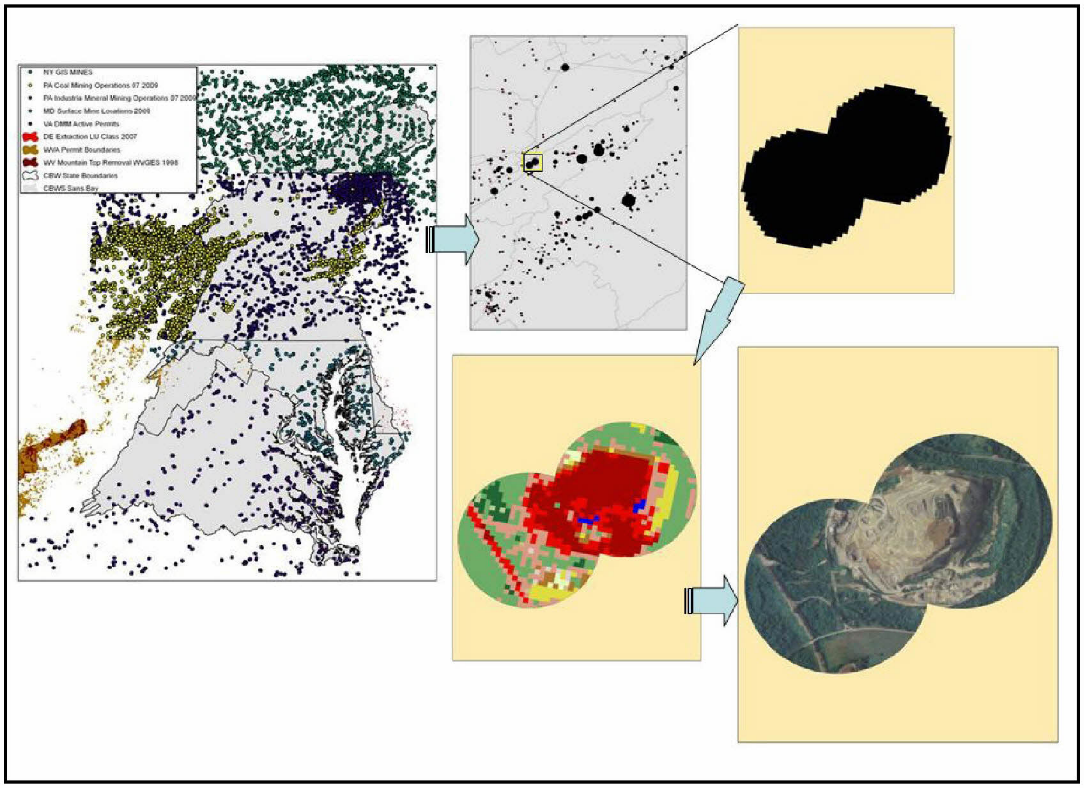


Figure 4-10. State surface mining data were converted to a raster mask and tabulated per land-segment. CBLCD Developed subclass acres under that ancillary mask had to be corrected.

4.2.8.4 Impervious Surface Developed Land Cover Coefficients

For the Chesapeake Bay Program Office, the RESAC (http://www.geog.umd.edu/resac/lc2.html) created a 2001 impervious surface data set of the Chesapeake Bay watershed. That data set was overlaid on the 2001 CBLCD to estimate the average percent of impervious surface within each of the four developed CBLCD classes (Table 4-4). The resulting impervious/pervious coefficients were used consistently across all years to determine the extent of impervious surfaces in the four developed land cover classes. The difference between the calculated impervious acreage and the original total developed class acreage within each land-river segment was classified as Pervious Developed. The same 2001 imperviousness coefficients were used similarly to compute all four years of the CBLCD data set because no comparable impervious data set was available to provide meaningful impervious surface-per-class coefficients for other years. The underlying assumption in that calculation is that mean watershed-wide percent imperviousness per developed class does not change significantly over time.

Table 4-4. Impervious surface coefficients for CBLCD developed land cover classes.

Land cover class	Impervious surface (%)	Pervious surface (%)
Developed Open Space (DOS)	6.57%	93.43%
Low Intensity Developed (LID)	18.19%	81.81%
Medium Intensity Developed (MID)	48.45%	51.55%
High Intensity Developed (HID)	75.94%	24.06%

4.2.8.5 Final Phase 5.3 Developed Land Uses

After adjusting the extent of the four CBLCD developed classes (DOS, LID, MID, and HID) to correct for possible confusion with the extractive class, the four developed classes were combined with the impervious surface coefficients to create eight developed classes: four impervious developed and four pervious developed. These eight classes were then recombined to form the final four developed or *urban* classes for the Phase 5.3 Model:

high-intensity developed impervious (Hi) = MIDi + HIDi
high-intensity developed pervious (Hp) = MIDp + HIDp
low-intensity developed pervious (Li) = DOSi + LIDi
low-intensity developed pervious (Lp) = DOSp + LIDp

The subscript *i* and *p* represent impervious and pervious portions of the four developed land cover classes.

Those four final developed land cover classes are described as follows:

- High-intensity impervious developed (Hi) lands contain more than 50 percent impervious surfaces per quarter-acre (on average) and generally represent impervious surfaces associated with large structures and major roads and include mostly commercial, industrial, and high-density residential land uses, interstates, and other major roads.

- *High-intensity pervious developed* (Hp) lands are immediately adjacent to high-intensity impervious developed lands and include mostly small landscaped areas and lands adjacent to developed structures and major roadways. No portions of the lands are impervious.

- *Low-intensity impervious developed* (Li) lands contain less than 50 percent impervious surfaces per quarter-acre (on average) and generally represent impervious surfaces associated with small structures and minor roads and include mostly low to medium density residential areas and some sidewalks and driveways.

- *High-intensity pervious developed* (Lp) lands are generally associated with low-intensity impervious developed lands and include residential lawns, golf courses, cemeteries, ball fields, developed parks, and other developed open spaces. Any impervious surfaces associated with these land uses are captured in either the low-intensity or high-intensity impervious developed classes depending on the size of the structure or road.

4.2.9 Final Phase 5.3 Calibration Tabular Land Use Data Set

The methods above were followed to create a tabular land use data set for 1984, 1992, 2001, and 2006 (Table 4-5). Data for all interim years were developed through linear interpolation.

Table 4-5. Final Phase 5.3 calibration land cover input categories.

Column heading	Data content
LRSEG	Watershed Modeling Segment Codes
open water	Open Water Acreage
extractive	Ancillary Extractive Acreage
Hi	High Developed Impervious Acreage Adjusted for Extractive
Hp	High Developed Pervious Acreage Adjusted for Extractive
Li	Low Developed Impervious Acreage Adjusted for Extractive
Lp	Low Developed Pervious Acreage Adjusted for Extractive
PH	Pasture Hay Acreage
CC	Cultivated Crop Acreage
Ag	Pasture/Hay + Cultivated Crop
% Pasture/Hay	LRSEG Pasture Hay acres as a percent of County Total
% Crop	LRSEG Cultivated Crop acres as a percent of County Total
% Ag	LRSEG Agriculture (PH + CC) acres as a percent of County Total

4.2.10 Southern Rivers Land Cover

This section outlines the major steps taken to develop a 2000 land cover data set for the Southern River Phase 5.3 land-river segments. The Phase 5.3 domain was divided into three zones on the basis of data availability (Figure 4-2). Zone 1 includes the Phase 5.3 study area north of Landsat row 35 and east of Landsat path 18. Zone 2 encompasses southern and southwestern Virginia in Landsat row 35 and Landsat path 18 (including the overlapping portion of Landsat scene 17:34). Zone 3 encompasses the Tennessee and North Carolina portions of the study area. Data availability is greatest in Zone 1 and least in Zone 3. Data available for Zone 1 include USGS CBLCD for 1984, 1992, 2001 and 2006, RESAC 2000 Impervious Cover and Agricultural and Population Census data. Data available for Zone 2 include partial coverage from the 2001 RESAC land cover data set, 1992 NLCD and Agricultural and Population Census data. Only the 1992 NLCD and the Agricultural and Population Census data are available for Zone 3.

For Zone 2, a 30-meter-resolution land cover database was pieced together using the best available data, which included the 2000 land cover data developed by the University of Maryland's RESAC and the 1992 NLCD.

For the southern rivers region, the 1992 NLCD data for North Carolina and Tennessee were merged and reclassified into 10 Phase 5.3 land cover classes. To update the total developed and developed extent of the 1992 NLCD data to the year 2000, a map of housing density was used to mimic the total extent of developed areas. The final Phase 5.3 land cover classification for zones 2 and 3 is outlined in Table 4-6.

Table 4-6. Phase 5.3 land cover classification compared to 1992 NLCD and 2000 RESAC classifications.

CBLCD or Phase 5.3 classes	1992 NLCD classes	2000 RESAC classes
Open Water (Water)	Open water (11)	Open water (1)
Low-Intensity Developed (LowInt_Urb)	Low-intensity developed (21) and all Barren, Transitional, Forest, Agricultural, or Recreational grasses classes within the housing density threshold	Low-intensity developed (3), developed trees/grasses (10–15), and forests and wetlands adjacent to highways with underlying impervious surfaces.
Extractive	Extractive (32)	Extractive (17)
(see Sec 4.5.1)	Bare and transitional (31, 33)	Barren (18)
Deciduous Forest (DecidF)	Deciduous forests and Woody wetlands (41, 91)	Deciduous forests and wetlands (20, 35) and developed deciduous trees adjacent to highways with no underlying impervious surfaces.
Evergreen Forest (EvergF)	Evergreen forest (42)	Evergreen forests and wetlands (21, 36) and developed evergreen trees adjacent to highways with no underlying impervious surfaces.
Mixed Forest (MixedF)	Mixed forest and Emergent wetlands (43, 92)	Mixed forests and wetlands (22, 38) and emergent wetlands (37) and developed mixed trees adjacent to highways with no underlying impervious surfaces.
Agriculture	Agriculture (81–84)	Pasture (25) and Cropland (26)
High-Intensity Developed (HighInt_Urb)	Medium/ High-intensity developed (22, 23)	Medium/High-intensity developed and Transportation (4, 5, 8) and all pixels meeting criteria for the P5 Low-intensity developed class with underlying impervious surfaces > 50%.
No Data	N/A	No Data (0)

The above methods were developed for Phases 5.0, 5.1, and 5.2 of the Watershed Model. The methods and data have not been updated since 2007, and the accuracy of the estimated extent of developed land uses over the 20-year hydrologic calibration period in Zones 2 and 3 is not comparable to the accuracy of the data and methods in Zone 1.

4.3 Agricultural Land Use

4.3.1 Use of Agricultural Census

Further divisions of agricultural land into various crops and pasture types required considerable attention. A detailed, spatially consistent, time-varying agricultural land use data was needed for the entire Phase 5.3 domain. Approximately one-quarter of the land in the Phase 5.3 domain is agricultural, which has high input loads of fertilizers and manures, and periods of relatively low cover during planting and harvesting operations. The high nutrient inputs and periods of low cover have the potential for high nutrient and sediment export from agricultural land. Accuracy in the agricultural acreage is essential to appropriately simulate nutrient and sediment loads.

Data from the U.S. Census Bureau *Census of Agriculture*, also called the Agricultural Census, for the years 1982, 1987, 1992, 1997, 2002, and 2007 were used to augment CBLCD agricultural acreage estimates. The Agricultural Census was used because it is the most complete agricultural survey available for the entire study area on a county scale, has a consistent spatial and temporal methodology, and is available every 5 years spanning the entire simulation period.

Acreage of specific crops in the Agricultural Census were combined to form seven Phase 5.3 agricultural land uses. Census crops with similar surface cover characteristics and fertilizer application rates were grouped and have similar nutrient loading properties. All agricultural acreage in the Census is accounted for in the Phase 5.3 agricultural classes. Phase 5.3 agricultural classes include *pasture, alfalfa, hay-unfertilized, hay-fertilized, degraded stream corridor, conventional tillage, conventional tillage with manure, and conservation tillage with manure*. Table 4-7 summarizes the county-level land use data contained in the U.S. Census of Agriculture and the census table in which the data are found.

Table 4-7. Agricultural land use data in U.S. Agricultural Census.

U.S. Agricultural Census table	U.S. Agricultural Census Data Category [a]	Census item number
Table 6: Farms, Land in Farms	Total cropland	060045
	Cropland used only for pasture or grazing	060049
	Cropland on which all crops failed	060055
	Cropland in cultivated summer fallow	060057
	Cropland idle	060059
	Pastureland, all types	060073
Table 26: Grains	Corn for grain or seed	260002
	Sorghum for grain or seed	260007
	Wheat for grain	260012
	Barley for grain	260042
	Buckwheat	260047
	Emmer and spelt	260067
	Oats for grain	260082
	Popcorn	260087
	Rye for grain	260102
	Sunflower seed	260112
	Triticale	260117
Table 27: Cotton, Tobacco	Cotton	270002
	Tobacco	270007
	Soybeans	270012
	Dry edible beans	270017
	Potatoes, excluding sweet potatoes	270042
	Sweet potatoes	270047
	Peanuts for nuts	270077
Table 28: Seeds, hay, forage, and silage	Hay-alfalfa, other tame, small grain, wild grass, silage, green chop, act.	280127

U.S. Agricultural Census table	U.S. Agricultural Census Data Category [a]	Census item number
	Alfalfa hay	280132
	Wild hay	280147
	Corn for silage or green chop	280157
	Sorghum for silage or green chop	280167
	Sorghum cut for dry forage or hay	280162
Table 29: Vegetables, sweet corn, and melons	Land used for vegetables	290002
Table 30: Land in Orchards	Land in Orchards, total	300002
Table 32: Berries harvested for sale	Berries	320002
Table 33: Nursery and Greenhouse Crops	Nursery and greenhouse crops, acres in the open	330003
Table 34: Other Crops	Corn cut for dry fodder, hogged, or grazed	340002
	Sorghum for syrup	340082
	Sorghum hogged or grazed	340087

Note:
a. All data are in harvested acres.

4.3.2 Agricultural Land Use Classification

How the different Agricultural Census crops aggregated into the Phase 5.3 land uses is summarized in Table 4-8 and outlined in more detail for each of the land use subsections below. In this report, names of cropland types estimated for the Phase 5.3 land use, and all Phase 5.3 land uses, are in italics.

Table 4-8. Aggregation of U.S. Agricultural Census land uses into the Phase 5.3 land uses.

Crop	Land use	Nutrient management	Tillage
alfalfa	*alfalfa*	N	NA
alfalfa	*alfalfa* nutrient management	Y	NA
barley	*conventional tillage with manure*	N	conventional
barley	*conventional tillage with manure* nutrient management	Y	conventional
barley	*conservation tillage with manure* nutrient management	Y	conservation
barley	*conservation tillage with manure*	N	conservation
berries	*conventional tillage*	N	conventional
berries	*conventional tillage* nutrient management	Y	conventional
buckwheat	*conventional tillage with manure*	N	conventional
buckwheat	*conventional tillage with manure* nutrient management	Y	conventional
buckwheat	*conservation tillage with manure* nutrient management	Y	conservation
buckwheat	*conservation tillage with manure*	N	conservation
corn dry fodder	*conventional tillage with manure*	N	conventional
corn dry fodder	*conventional tillage with manure* nutrient management	Y	conventional
corn dry fodder	*conservation tillage with manure* nutrient management	Y	conservation
corn dry fodder	*conservation tillage with manure*	N	conservation
corn grain	*conventional tillage with manure*	N	conventional
corn grain	*conventional tillage with manure* nutrient management	Y	conventional
corn grain	*conservation tillage with manure* nutrient management	Y	conservation

Crop	Land use	Nutrient management	Tillage
corn grain	*conservation tillage with manure*	N	conservation
corn silage	*conventional tillage with manure*	N	conventional
corn silage	*conventional tillage with manure* nutrient management	Y	conventional
corn silage	*conservation tillage with manure* nutrient management	Y	conservation
corn silage	*conservation tillage with manure*	N	conservation
cotton	*conventional tillage*	N	conventional
cotton	*conventional tillage with manure* nutrient management	Y	conventional
dry beans	*conventional tillage with manure*	N	conventional
dry beans	*conventional tillage with manure* nutrient management	Y	conventional
dry beans	*conservation tillage with manure* nutrient management	Y	conservation
dry beans	*conservation tillage with manure*	N	conservation
emmer spelt	*conventional tillage with manure*	N	conventional
emmer spelt	*conventional tillage with manure* nutrient management	Y	conventional
emmer spelt	*conservation tillage with manure* nutrient management	Y	conservation
emmer spelt	*conservation tillage with manure*	N	conservation
failed crops	*hay-fertilized* nutrient management	Y	NA
failed crops	*hay-fertilized*	N	NA
fallow land	*hay-unfertilized*	N	NA
idle land	*hay-unfertilized*	N	NA
nursery	*nursery*	N	NA
oats	*conventional tillage with manure*	N	conventional
oats	*conventional tillage with manure* nutrient management	Y	conventional
oats	*conservation tillage with manure* nutrient management	Y	conservation
oats	*conservation tillage with manure*	N	conservation
orchards	*conventional tillage without manure*	N	NA
pasture	*pasture*	N	NA
pasture	*pasture* nutrient management	Y	NA
peanuts	*conventional tillage without manure*	N	conventional
peanuts	*conventional tillage w/o manure* nutrient management	Y	conventional
popcorn	*conventional tillage with manure*	N	conventional
popcorn	*conventional tillage with manure* nutrient management	Y	conventional
popcorn	*conservation tillage with manure* nutrient management	Y	conservation
popcorn	*conservation tillage with manure*	N	conservation
rye	*conventional tillage with manure*	N	conventional
rye	*conventional tillage with manure* nutrient management	Y	conventional
rye	*conservation tillage with manure* nutrient management	Y	conservation
rye	*conservation tillage with manure*	N	conservation
sorghum grain	*conventional tillage with manure*	N	conventional
sorghum grain	*conventional tillage with manure* nutrient management	Y	conventional
sorghum grain	*conservation tillage with manure* nutrient management	Y	conservation
sorghum grain	*conservation tillage with manure*	N	conservation
sorghum silage	*conventional tillage with manure*	N	conventional
sorghum silage	*conventional tillage with manure* nutrient management	Y	conventional
sorghum silage	*conservation tillage with manure* nutrient management	Y	conservation
sorghum silage	*conservation tillage with manure*	N	conservation
soybeans	*conventional tillage with manure*	N	conventional

Crop	Land use	Nutrient management	Tillage
soybeans	*conventional tillage with manure* nutrient management	Y	conventional
soybeans	*conservation tillage with manure* nutrient management	Y	conservation
soybeans	*conservation tillage with manure*	N	conservation
sunflower	*conventional tillage with manure*	N	conventional
sunflower	*conventional tillage with manure* nutrient management	Y	conventional
sunflower	*conservation tillage with manure* nutrient management	Y	conservation
sunflower	*conservation tillage with manure*	N	conservation
sweet potatoes	*conventional tillage without manure*	N	conventional
sweet potatoes	*conventional tillage w/o manure* nutrient management	Y	conventional
tame hay	*hay-fertilized* nutrient management	Y	NA
tame hay	*hay-fertilized*	N	NA
tobacco	*conventional tillage without manure*	N	conventional
tobacco	*conventional tillage w/o manure nutrient management*	Y	conventional
triticale	*conventional tillage with manure*	N	conventional
triticale	*conventional tillage with manure* nutrient management	Y	conventional
triticale	*conservation tillage with manure* nutrient management	Y	conservation
triticale	*conservation tillage with manure*	N	conservation
vegetables	*conventional tillage without manure*	N	conventional
vegetables	*conventional tillage w/o manure* nutrient management	Y	conventional
wheat	*conventional tillage with manure*	N	conventional
wheat	*conventional tillage with manure* nutrient management	Y	conventional
wheat	*conservation tillage with manure* nutrient management	Y	conservation
wheat	*conservation tillage with manure*	N	conservation
white potatoes	*conventional tillage without manure*	N	conventional
white potatoes	*conventional tillage* nutrient management	Y	conventional
wild hay	*hay-unfertilized*	N	NA

4.3.2.1 Hay-Fertilized

Hay with nutrients includes all tame and small grain hay excluding wild hay or alfalfa, which are included in other categories. Those crops receive fertilizer and have a high degree of surface cover for most of the year. Failed cropland is also included in this category because they receive fertilizer but are not harvested, a pattern most similar to *hay-fertilized*.

Hay-fertilized =

(Hay-alfalfa, other tame, small grain, wild grass, silage, green chop, act.) – (Wild hay) – (Alfalfa) + (Cropland on which all crops failed).

4.3.2.2 Hay-Unfertilized

The *hay-unfertilized* category includes hay or other herbaceous agricultural areas that do not receive fertilizer and are not harvested, such as wild hay, idle cropland, and fallow land.

Hay-unfertilized =

(Wild hay) + (Cropland idle) + (Cropland in cultivated summer fallow)

4.3.2.3 Alfalfa

This category contains only alfalfa hay. This is a dominant hay crop in many areas of the watershed. *Alfalfa* is a separate hay category because it is a nitrogen-fixing, leguminous crop and receives different nutrient applications than other hay crops.

4.3.2.4 Conventional or Conservation Tillage with Manure

The *conventional tillage with manure* and the *conservation tillage with manure* categories contain grain, corn, soybeans, and dry beans. Wheat, corn, and soybeans are the dominant crops in the Chesapeake watershed, often planted in a 2-year rotation on the same parcel of land. Crops in this category receive nutrient inputs from manure application as well as fertilizer. This is the highest percentage of cropland in the Chesapeake watershed. On average, 90 percent of total cropland is estimated to be in this category.

Conventional tillage with manure and the conservation tillage with manure =

(Wheat for grain) + (Barley for grain) + (Buckwheat) + (Emmer and spelt) + (Oats) + (Popcorn) + (Rye for grain) + (Sunflower) + (Triticale) + (Corn for grain) + (Corn for silage or green chop) + (Sorghum for grain or seed) + (Sorghum for silage or green chop) + (Soybeans) + (Dry beans) + (Canola) + (Mushrooms)

Information from the Conservation Technology Information Center (CTIC 1989–2004) provides annual information by county of the splits between the conventional and conservation tillage acres for these two crop land uses. The CTIC National Crop Residue Management Survey lists the percent under conservation tillage for corn, small grain, soybeans, and sorghum on a county level for each year starting in 1989. The percent under conservation tillage for the composite crop is calculated as a weighted average of the individual crop percentages, using crop acreage as a weight. Tillage practices for 1989 are used for the Agriculture Census years 1982 and 1987.

4.3.2.5 Conventional Tillage without Manure

The *conventional tillage without manure* category contains cotton, tobacco, and vegetables. Because most of these crops are grown for direct human consumption, there is generally no manure application. These crops are simulated as only grown with a conventional tillage system. Orchards are also included in this category.

Conventional tillage without manure =

(Cotton) + (Tobacco) + (Land used for vegetables) + (Potatoes, excluding sweet potatoes) + (Sweet potatoes) + (Berries) + (Nursery acres in the open) + (Land in orchards) + (short rotation woody crops) + (sod) + (melons) + (Peanuts)

4.3.2.6 Pasture

The *pasture* category contains only the pastureland item from the Agricultural Census. The Phase 5.3 simulated *pasture* receives directly excreted manures. Manure applications to pasture from collected and stored manures also occur in many cases where manures are in excess of row crop need in the land-segment. The Agricultural Census underreports pasture area used for horse grazing because horses are not considered to be agricultural commodities.

4.3.2.7 Degraded Riparian Pasture

The *degraded riparian pasture* land use represents unfenced riparian pasture with an associated stream degraded by livestock. The *degraded riparian pasture* land use receives only directly excreted manure. However, the direct excretion rate is nine times that of *pasture* because of the greater frequency of loafing of pastured animals in riparian areas. The area of this land use is set at 1 percent of the *pasture* land use. *Degraded riparian pasture* is treated by riparian buffer BMPs.

4.3.2.8 Nutrient Management Pasture

Nutrient management pasture is pasture that is part of a farm plan where crop nutrient management is practiced. In Phase 5.3, *nutrient management pasture* and *pasture* have the same nutrient application rates that are applied to each at the same time.

4.3.2.9 Animal Feeding Operations

Another agricultural land use category employed in Phase 5.3 is the land use of *animal feeding operations*. Animal production areas are generally those areas around barns and where manure storage is most likely to occur. The Chesapeake Bay Program names these areas AFOs. The areas are where manure is lost during storage and handling is applied (Brosch 2010).

Using Number of Farms to Determine Animal Feeding Operations Area

The number of farms for each animal type is also taken from the censuses (Table 4-9). The number of farms informs the acres assigned for the *Animal Feeding Operation* land use category. As with the other data from the National Agriculture Statistic Service (NASS) Agricultural Census, these data are selected for each county, state, and year.

Table 4-9. Agricultural Census number of farms.

Table name	Item name	Unit
Cattle and calves—Inventory and Sales	Cattle and calves	no. of farms
Hogs and Pigs—Inventory and Sales	Total hogs and Pigs	no. of farms
Poultry—Inventory and Sales	Any Poultry	no. of farms
Sheep and Lambs—Inventory, Wool Production, and Number Sold	Sheep and Lambs—Inventory	no. of farms
Milk Goats	Milk goats inventory	no. of farms
Angora Goats	Angora goats inventory	no. of farms

Deriving the Area for Animal Feeding Operations

AFO land areas are added to existing agricultural land use areas using the following criteria.

1. For each county and year, multiply the number of farms for each animal type by the appropriate value found in Table 4-10.

2. AFO acres are added to the agricultural acres.

3. AFOs are broken down into land segments, and later into land-river segments, using an area weighted average based on the amount of agriculture in the county. The acres of AFOs in the county are multiplied by the agricultural acres in each land-river segment and divided by the total agricultural acres in the county. Agricultural acres are defined as those in the land uses:
   - animal feeding operations
   - alfalfa
   - row without manure
   - row with manure
   - hay without nutrients
   - hay with nutrients
   - pasture
   - degraded riparian pasture
   - nursery

Table 4-10. Animal feeding operation acres/farm by animal type.

Item name	Acreage/farm
Cattle and calves	0.5
Total hogs and Pigs	0.2
Any Poultry	0.25
Sheep and Lambs	0.1
Milk goats	0.05
Angora goats	0.05

The Agricultural Census lists farms by animal type only, yet many farms have more than one animal type. Certain acreages are designated for each farm with an animal type; therefore, areas that are shared by more than one species of animal are overestimated.

The land area of the farm is not related to the AFO size, but rather the size of an animal type and the number of animals.

On AFO land, the following animal types are not captured: other poultry (such as ducks, geese, emus, ostriches and squab) or miscellaneous livestock and animal specialties (such as bison, llamas, and rabbits). It is assumed that few farms exist with significant acreage specializing solely in those animals, so that land area is captured under other animal types.

4.3.2.10 Nursery

In the Phase 5.3 simulation, the *nursery* land use represents container nurseries, which typically have a high density of plants (10–100 plants per square meter) and high rates of nutrient applications. Annual fertilizer application rates are in the range of 76–128 pounds of nitrogen per acre and 44–45 pounds for the annual per acre application rates of phosphorus.

Field nurseries are also accounted for in the Phase 5.3 land use, but because those nurseries essentially grow plants in the ground, which are fertilized at relatively low rates of about 60–100 pounds of nitrogen per year, they are contained in the *conventional tillage without manure* land use.

In the Agricultural Census, nurseries are reported as “total square footage under glass” and “acres in the open.” It is assumed that this represents the container and field nurseries, respectively. The *nursery* category simulated in Phase 5.3 represents the total square footage under glass reported in the Agricultural Census and converted to acres, the common unit of area in Phase 5.3. All nursery crops grown in the open including bedding and flowering plants, cut flowers and floral greens, foliage plants, cut Christmas trees, and sod are represented as *conventional tillage without manure*. In the Agricultural Census, the nurseries under glass typically represent about 1 percent of the “acres in the open” nursery category.

4.3.3 Method for Estimating Data Gaps in Agricultural Census Data

NASS withholds data that could identify any particular farm operation. Withheld data are reported as *D*. When withholding one county’s data could identify a farm in a neighboring county, the neighboring county is reported as D also. This situation is likely to occur where there is a single large farm operation of a specific type in one county and zero farm operations of that type in the neighboring county. The NASS Census reports data on a county scale and as a state total. Data for omitted counties are combined in the Census and presented as “all other counties.” Counties may report a D in one year, yet report in other years. Procedures for estimating a D value are listed below (Brosch 2010).

First, a linear interpolation is made for the non-reported value between prior and subsequent Agricultural Census years for which values were reported. The interpolation is for county and state scales. If the interpolation causes the sum of counties to be greater than the reported state values for that item in that year, method two is used. If 30 percent or more of all counties in a state can not be done with that method, proceed to method two.

Method two is used where there is no reported value for prior and subsequent years, then the difference between the state total and the sum of the counties is parsed between all the counties that were listed as D. The data listed for *All Other Counties* represent the sum of the data for all counties in which data were omitted (denoted by an *N* in the electronic version of the Agricultural Census). Parsing of the omitted data is done in proportion to the average of the datum in that county to the state total for each year where there are reported data. That average is calculated as the ratio of the average of the item in that county for any reported years to the state total for that same year.

Then, where there is no reported state value for any Agricultural Census year and the state value is listed as D, a linear regression is performed over all Agricultural Census years. Where there is no reported value for any Agricultural Census year, the difference between the state total and the sum of the counties is parsed in proportion to agricultural land area in the county to the state for the year in question. Agricultural land areas are from the Agricultural Census table Farms, Land in Farms, Value of Land and Buildings, and Land Use. Items from that table include *Total Cropland*, and *Pastureland and Rangeland other than cropland and woodland pastured*. (When converted to Chesapeake Bay Program land uses, those include pasture, degraded riparian pasture, hay with nutrients, hay without nutrients, high till without manure, high till with manure, low till with manure, nutrient management pasture, nutrient management hay, nutrient management alfalfa, nutrient management high till without manure, nutrient management high till with manure, nutrient management low till, and animal feeding operations). That is done for each year. The total of all the counties, reported and estimated, should be no greater than the state total for the year. If the total of all the counties is greater than the state total and there is a county that reported zero agricultural land uses, that county's animal population is set to zero. For land or crop areas, the counties are reduced proportionally.

Crop area and crop yield are related data and cannot be estimated independently. Where *yield is reported and acres are withheld* for a crop in a county, the acres are estimated from the yield. The NASS Census reports yields as total yield, and not yield/acre, so it is possible to estimate those acres directly from the yield. The procedures below address situations where the yields are reported and acres are withheld.

1. Determine the average yield/acre for the state from reported data for that year where pairs (acres, yield) are available. Where there are less than three values and an average cannot be determined, use the average from that state among any years.
2. For areas without reported pairs, use the theoretical maximum yield for the average yield/acre.
3. Calculate state totals where not reported
4. For all pairs where acres were not reported, divide the reported yield for that county and crop type by the average yield of that crop type.
5. Check that the sum of the calculated acres equals the total reported for the acres of that crop type in the state. In each of the cases below, follow the same procedure to adjust the yields to match the state yield value.
   a. If the sum of the calculated county acres are 10 percent > state total and the state acre was reported, not calculated, then decrease the yield so that the calculated acres have the average yield. (Note: this assumes that the yield was incorrectly reported.) Where the state acres are exceeded, set the remaining yields and acres pairs to zero where neither acres nor yields were reported.
   b. If the calculated county acres are 10 percent less than or 10 percent greater than the state total and the state acre was calculated, then adjust the calculated state acres total to accommodate the calculated county acres. (Note: This assumes that the state acres were incorrectly calculated.)
   c. If the calculated county acres are 10 percent < state total and the state acre was reported, not calculated, increase the county acres proportional to that area. (Note: This will result in lower than average yields.)
   d. If the acres are within 10 percent of the state total, adjust the county acres to match the state acres proportional to the calculated county area.
6. For all pairs where yield were not reported, multiply the acres by the average yield to get yield.
7. If a yield adjustment is done, such as the acres adjustment where the calculated yields would be reduced to match the state reported yield where all counties in state have either reported yields or yields calculated in the method in step 6 immediately above, calculate the yield by multiplying the calculated acres by the average yield for all pairs missing yield. Note that this step, if necessary, would have to be done before acres having the withheld data estimated.

Where *both acres and yields are withheld*, estimate acres first using the Agricultural Census classification for withheld data and proceed as with the scenario of acres reported and yield withheld.

Where *acres are reported but yields are withheld*, use the average yield/acre for the state from the same year. If the average yield cannot be calculated because of fewer than two values being reported, use the state value. If the state value is withheld, use the theoretical maximum yield as defined in Section 5 or the Scenario Builder documentation (Brosch 2010).

4.3.4 Accounting for Double-Cropping

When a farmer plants a summer crop followed by a winter crop, two different crops can exist on the same acre of land. Such a situation is termed double-cropping. Double-cropping is accounted for in Scenario Builder by determining the amount of land available to be double-cropped and subtracting the actual acres of crop types that are eligible to be double-cropped. That requires identifying pairs of crop types that are typically cropped one after the other (Table 4-11).

Table 4-11. List of crops eligible for double cropping.

Major land use	Crop name	First crop?	Second crop?
Row with manure	Barley for grain Harvested Area	--	Yes
Row with manure	Buckwheat Harvested Area	--	Yes
Row with manure	Canola Harvested Area	Yes	--
Row with manure	Corn for Grain Harvested Area	Yes	--
Row with manure	Corn for silage or greenchop Harvested Area	Yes	--
Row with manure	Dry edible beans, excluding limas Harvested Area	--	Yes
Row with manure	Emmer and spelt Harvested Area	--	Yes
Row with manure	Oats for grain Harvested Area	Yes	--
Row with manure	Popcorn Harvested Area	Yes	--
Row with manure	Rye for grain Harvested Area	--	Yes
Row with manure	Sorghum for Grain Harvested Area	Yes	--
Row with manure	Sorghum for silage or greenchop Area	Yes	--
Row with manure	Soybeans for beans Harvested Area	--	Yes
Row with manure	Sunflower seed, oil varieties Harvested Area	Yes	--
Row with manure	Triticale Harvested Area	--	Yes
Row with manure	Wheat for Grain Harvested Area	--	Yes

To determine the area for double-cropping, the total harvested area (single line item in Agricultural Census) is reduced by the area of ineligible crops. If the result is negative, there are no double crops. Positive acreage is compared to the sum of area for all crops above (double-croppable). If double crop acreage is less than total harvested minus double crop ineligible, no double crops exist. If the double crop area exceeds the harvested area, the difference is the acreage of double crops. Proportions of this acreage from each first crop set and each second crop set are based on acreage from each crop to the total.

For example, if corn is 50 percent, sunflower seed-oil is 2 percent, and sorghum is 48 percent of land acreage as reported in the Agricultural Census, the number of acres double-cropped will be covered by 50 percent corn, 2 percent sunflower seed-oil, and 48 percent sorghum (That example assumes there are enough acres of the first crop to accommodate all acres of the second double-croppable crop).

Finally, the acres are marked as double-cropped to have independent plant and harvest dates. If the acres of the second crops or first crops are imbalanced, the remainder is single-cropped and the harvested area is adjusted. For example, if first crops are 300 acres and second crops are 50 acres and total harvested area is 100 acres, the total harvest acreage is increased to 300 acres where 50 are double cropped. That can be done to accommodate second crops too.

4.4.5 2002 Agricultural Census Methodology Change

In 2002 a methodology change occurred in the way the National Agriculture Statistic Service (NASS) reported Census of Agriculture data. The 2002 Census data include a *coverage adjustment*. The adjustment was made to estimate agricultural land not accounted for in the census because of inaccuracies in the census mail list. The largest source of coverage error in the census is because of farmland that was inadvertently left off the census mail list. That results in a slight increase in crop acreage after the coverage adjustment. In some cases, however, farmland was duplicated on the census mail list. That can occur when a farm has dual ownership or there is a change in ownership and results in a decrease in crop acreage after the coverage adjustment. The 2002 Census is more accurate because of the adjustment; however, because of the methodology change, it is incompatible with previous censuses.

In 2002 as with each subsequent Agricultural Census, the prior census data with revisions are reported. Data are obtained from the latest Agricultural Census that reports any year's data. Where a category was not reported in revised data, the data from the original publication of that year's census were obtained. Major revisions occurred in 2002, and only a portion of 1997 data was revised. The unrevised categories were culled from the original publication of the 1997 Census (Brosch 2010).

NASS first employed a sampling methodology in the 1982 Census. Previously, the Agricultural Census was compiled from direct enumeration. In 2002 NASS changed its sampling methodology for the census to address underreporting. NASS used statistical methods to determine where underreporting was likely and targeted efforts to improve the response rate in those areas. NASS revised the 1997 Agricultural Census using statistical methods to make the 1997 data comparable to the 2002 data. The categories in the revised 1997 Agricultural Census published in 2002 that were not adjusted and annotated as NA were those that were new categories in 2002. In those cases, the original 1997 data were used. Adjustments for the 1982, 1987, and 1992 Agricultural Censuses are unavailable. For those years, NASS recommends against making adjustments (Barbara Rater, Maryland NASS, personal communication, April 14, 2008 and Jim Burt, NASS National Office).

4.5 Development of the Forest, Woodlots, and Wooded and Harvested Forest Land Uses

4.5.1 Forest, Woodlots, and Wooded

The Phase 5.3 *forest, woodlots, and wooded* land use includes woodlands, woodlots, and usually any wooded area of 30 meters by 30 meters remotely sensed by spectral analysis. The *forest, wood lots, and wooded* land use is the predominant land use in the Chesapeake watershed. Without the detail of separate wetland categories in Phase 5.3, the most representative land use category to include forested and emergent nontidal wetlands was in the *forest, woodlots, and wooded* land use. Accordingly, the low-loading, low-nutrient input land use of wetlands were included in the land use. For computational reasons, tidal wetlands were considered to be part of the domain of the tidal Chesapeake Bay WQSTM. Specifically, the *forest, woodlots, and wooded* land use in the Phase 5.3 Model is found by subtracting all the agricultural, developed, extractive, and *open water* lands uses from the total acres in each land-river segment.

4.5.2 Harvested Forest

The Phase 5.3 *harvested forest* area is estimated to be about 0.33 percent of the *forest, woodlot, and wooded* land use everywhere in the Phase 5.3 domain. The period of time the disturbed forest exports high sediment loads is another problem for the HSPF structure. The literature suggests that a return to sediment export rates of undisturbed forest occurs after about 3 to 5 years (Arthur et al. 1998; Castro et al. 1997; Wang et al. 2003; Riekerk et al. 1998).

With only two wooded land uses of *forest/woodlot* and *harvested forest*, simulating the slow return of nutrient exports to the undisturbed forest rate is impractical and simplifying assumptions have to be made. Accordingly, the *harvested forest* nutrient export rates are applied in the simulation for the area of harvested forest for a single year, with an estimated forest harvest rate of 1 percent of forest annually.

Another forest disturbance that reduces forest cover and increases runoff and erosion is fire, which can also be included in this land use category to the degree the available data on the amount of land involved allow.

4.6 Extractive–Active and Abandoned Mines, Bare–Construction, and Other Minor Land Uses

4.6.1 Bare-Construction

Construction (also known as bare-construction) lands are not measured with satellite imagery whereas the other four developed classes are directly measured using satellite imagery. Instead, the area of construction is assumed to encompass an area of land 2.5 times the annual change in impervious surfaces in a watershed modeling segment. So if we estimate that the amount of impervious surfaces increased by 10 acres per year in modeling segment X, we would assume that the 25 acres was under construction each year in modeling segment X.

Bare-construction is an important land use because of its high sediment-loading capacity. Very little data are available for yearly construction acreage on a state or county level. To obtain the *bare-construction* land use, the annualized difference between the estimated extent of impervious land in 1984, 1992, 2001, and 2006 (derived from the 2000 RESAC impervious surface coefficients and the CBLCD) was used. The amount of impervious land, which increased over the 10-year period, was assumed to have been through a transition to a *bare-construction* land use. Figure 4-11 is a representation of the 10-year change in estimated imperviousness between 1990 and 2000.

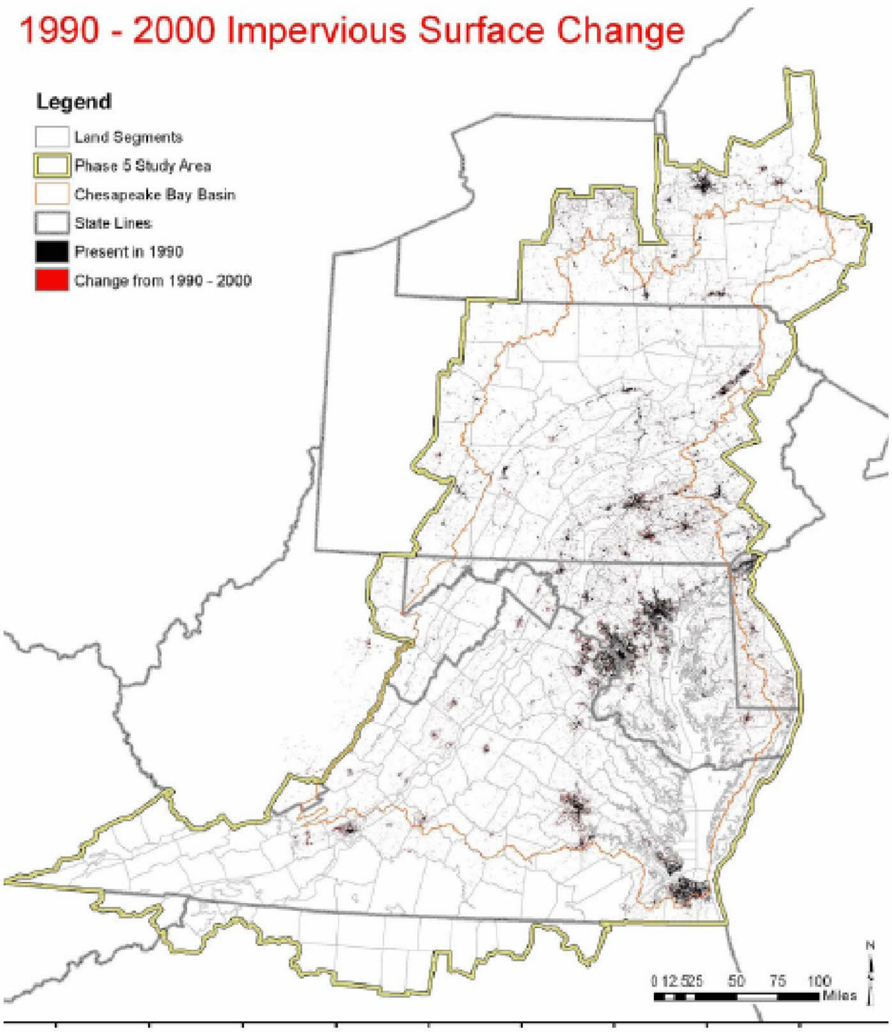


Figure 4-11. Change in impervious area from 1990 to 2000

The average yearly change in impervious surface in a segment is a good relative estimate of construction; however, it underestimates the area cleared by construction. Generally during the construction phase, more acres of land are cleared than end up as impervious surface and contribute to the sediment load from the construction area. Detailed records from all Maryland counties indicate that, on average, a unit area of imperviousness is generated from a construction permit covering about 10 times that impervious area but that the area cleared for construction was 2.5 times the impervious area, or on average one-quarter of the total area of the site covered by the construction permit. Accordingly, the average yearly change in impervious surface was multiplied by 2.5 to calculate the Phase 5.3 *bare-construction* acreage. Although that calculation is static and does not reflect year-to-year changes in construction, it provides a uniform methodology for the entire Phase 5.3 study area.

Maryland permit data are available for state totals for the years 1998, 1999, 2001, 2002, 2003, and 2004. Phase 5.3 bare-construction area annual estimates for Maryland (here multiplied by a factor of four for consistency with total permitted construction acres as described above) fall within these reported values (Figure 4-12).

For 2006 construction was added into the land use after the adjustment was made for the Agricultural Census. To keep the total area fixed, the acres of construction were taken from forest and extractive in the proportion that they are present in the land river segment. In other land use years, construction was considered a fixed land use with agriculture and developed, and the remaining area in a land-river segment was parsed as described as described previously.

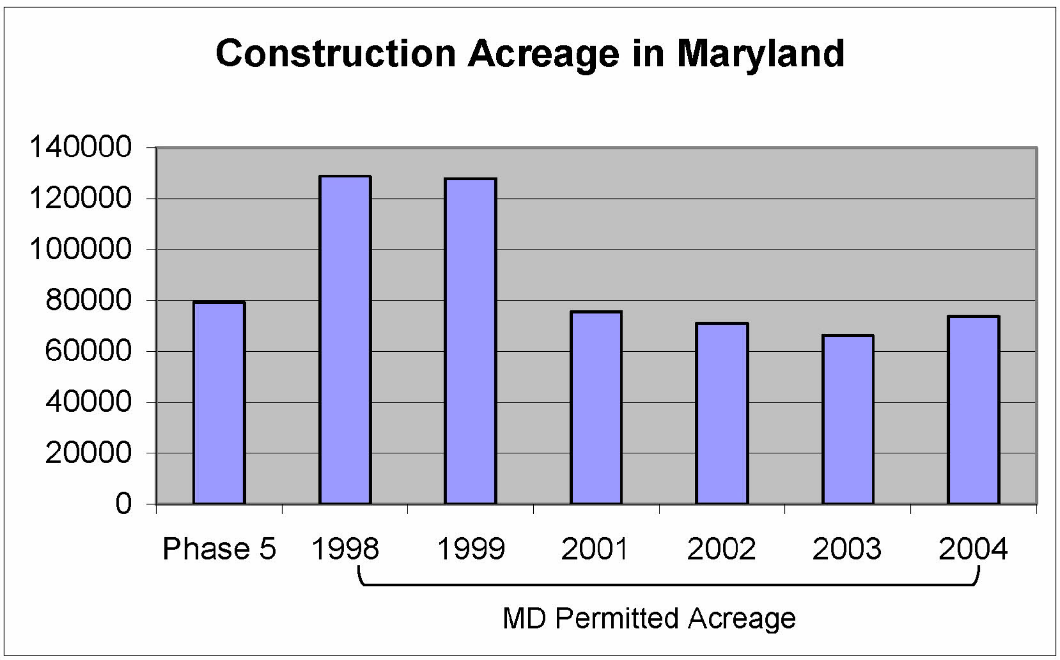


Figure 4-12. Permitted construction area in Maryland for 1998 to 2004 compared to the Phase 5.3 annual average bare-construction (bare-construction multiplied by a factor of four as described in the text) area.

4.5.2 Extractive-Active and Abandoned Mines

The *extractive-active and abandoned mines* land use is composed of mines, gravel pits, and the like. Federal and state laws in the early 1980s regulated active working mines and applied effluent limits of about 70 mg/L total suspended solids from mine effluent. Abandoned mines have, of course, no effluent limits. Development of the Phase 5.3 *extractive-active and abandoned mines* land use from the CBLCD is described in Section 4.2.6.

4.5.3 Open Water

Open water area was estimated directly from the 2000 RESAC land use data. Tidal water is outside the Phase 5.3 domain, so only nontidal waters were quantified as the Phase 5.3 *open water* land use. The tidal and nontidal waters were differentiated by applying a NOAA high-resolution shoreline of tidal waters (NOAA 1994). Unlike other Phase 5.3 land uses, open water land use has a constant area and is unchanged over the 1985 to 2005 simulation period.

4.5.4 MS4 Areas

Developed areas that are part of municipal separate storm sewer systems (MS4s) are tracked separately in the Phase 5.3 Model. An *MS4 area* in the Phase 5.3 Model is assumed to be an area under specific stormwater regulations administered by the states. MS4s are a regulated discharge of stormwater. The first phase of the program (Phase I) required certain industrial dischargers, medium and large MS4s, and operators of construction sites greater than 5 acres to obtain a National Pollutant Discharge Elimination System (NPDES) permit. Medium MS4s are associated with municipalities with a population of 100,000 to 249,999 and large MS4s with a population of 250,000 or more. All other MS4s are considered small MS4s and are regulated in the Phase 2 MS4 program (USEPA 2000). The Phase 5.3 Model simulates both Phase I and Phase II *MS4 areas*.

The estimated *MS4 areas* were provided by each of the Chesapeake watershed states and represent the best current understanding of *MS4 areas*. While the best and final definition of an MS4 is delineated sewersheds, most jurisdictions can provide only municipal boundaries as an estimated MS4 area. Only the developed land is differentiated as being a contributor to the stormwater load in a simulated Phase 5.3 *MS4 area*. If the developed land is within or outside an *MS4 area*, the developed land was simulated the same and is differentiated only as a load contributing to an *MS4 area* or not.

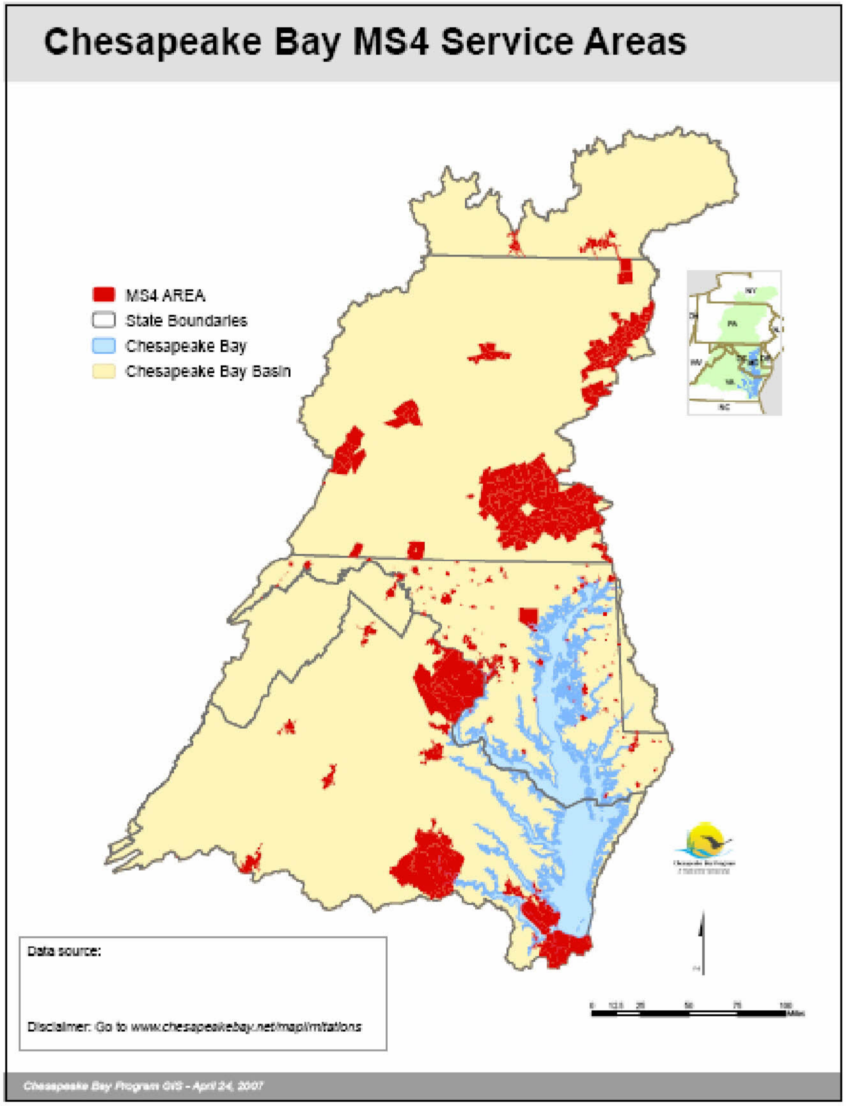


Figure 4-13. MS4 areas in the Chesapeake watershed.

4.6 Final Land Use for the Phase 5.3 Simulation Period of 1985–2005

A comparison of the Phase 4.3 and Phase 5.3 land use categories is in Table 4-12. Phase 5.3 expanded many of the land uses in Phase 4.3. For example, both Phase 4.3 and Phase 5.3 have the *forest, woodlots, and wooded* land use, but only Phase 5.3 has the land use of harvested forest. In Phase 4.3, the assumption was that the harvested forest portion was generally represented within the overall *forest, woodlots and wooded* land use. Figures 4-20 through 4-36 graphically depict the Phase 5.3 land use and segmentation.

Table 4-12. Major land use/land cover types in the watershed model comparing Phase 5.3 to Phase 4.3 version.

Model Land Uses	Phase 4.3	Phase 5.3
Forest		
Forest, Woodlots, & Wooded	✓	✓
Harvested Forest		✓
Agriculture		
Conventional Tillage Receiving Manure	✓	✓
Conventional Tillage Not Receiving Manure		✓
Conservation Tillage Receiving Manure	✓	✓
Hay Land	✓	✓
Alfalfa	✓	✓
Hay With Nutrients		✓
Hay w/o Nutrients		✓
Pasture	✓	✓
Nursery		✓
Developed Land		
Pervious	✓	
Impervious	✓	
Mixed Open	✓	
Low-Intensity Developed Pervious		✓
Low-Intensity Developed Impervious		✓
High-Intensity Developed Pervious		✓
High-Intensity Developed Impervious		✓

4.7 Estimates of Future Land Use

4.7.1 Motivation Future Land Use Estimates

A major challenge is maintaining Chesapeake restoration progress despite continued population and urban development. Over the past 30 years, the population of the Chesapeake Bay watershed has increased by more than 4 million persons. From 1980 to 2000, the Chesapeake Bay experienced the greatest increase in population compared to other coastal watersheds in the nation (Crossett et al. 2004). According to 2009 estimates, population of the Bay watershed exceeds 17 million. County population projections produced by state agencies indicate that the population will increase by an additional 3 million through the year 2030. If current development trends continue, urban land in the Chesapeake Bay watershed could increase by 60 percent from 2000 levels through the year 2030 (Boesch and Greer 2003). EPA's Office of Inspector General reported that development growth is outpacing progress in watershed efforts to restore the Chesapeake Bay (USEPA 2007).

4.7.2 Scale of Chesapeake Bay Land Change Model Future Land Use Estimates

To meet the data requirements of the Phase 5.3 Model, the Chesapeake Bay Land Change Model (CBLCM) forecasts change at the land-river-segment scale. Because the land-river-segments are nested within counties, all data generated at the land-river-segment scale can also be provided at the county scale.

4.7.3 Components of CBLCM Future Land Use Estimates

Researchers from the USGS, EPA, Shippensburg University, and a private consultant developed the CBLCM which combines the strengths of *GAMe* (**g**rowth **a**llocation **m**odel) (Reilly 2003), with those of a cellular automata model, *SLEUTH* (**s**lope, **l**and use, **e**xcluded land, **u**rban extent, **t**ransportation, and **h**illshade) (Clarke et al. 1997; Jantz et al. 2003). GAMe projects future urban area at the watershed modeling segment scale by fitting total housing unit trends over the 1990s to a Gompertz (exponential S-shaped) curve, which is then used to extrapolate housing trends to the year 2030. County population projections converted to county-scale estimates of total housing demand were used to constrain the modeling segment scale forecasts generated using the Gompertz curve. After the model segment scale forecasts of housing demand were adjusted to match the county-scale housing demand totals, they were converted to an estimate of future developed land area using segment specific ratios of developed land cover area to total housing units.

The proportions of urban growth occurring on farmland, forest land, sewer, septic, and within existing developed area boundaries were determined uniquely for each watershed modeling segment using the SLEUTH urban growth model, a stochastic cellular automata model customized for application in the Chesapeake Bay watershed (Jantz et al. submitted; Goetz and Jantz 2006). SLEUTH extrapolates historic rates and patterns of urban growth into the future using satellite derived imagery of 1990 and 2000 impervious cover. SLEUTH was calibrated separately in 15 different county-clusters in the Bay watershed. Counties were clustered by shared characteristics of urban growth, commuting patterns, and state and ecoregion boundaries. SLEUTH uses a Monte Carlo method to generate multiple simulations of future growth, which are combined to create a probability map of future urban development. The output from SLEUTH is a 30-meter resolution probability raster data set that indicates the probability of urban growth in the year 2030 with values ranging from 0 to 100 percent. The patterns of probable growth vary for each cluster of counties according to the coefficients used to calibrate SLEUTH in each cluster.

The patterns and levels of probable urban growth can also vary within a county by local factors of attraction and repulsion. Those factors are represented in a 30-meter resolution raster data set referred to as an *exclusion layer*. Local areas *off limits* to development can include public lands, conservation easements, rurally zoned lands, steep slopes (greater than 21 percent grade), emergent wetlands, and open water.

For the Bay watershed, an exclusion layer was created in a GIS using information on public and protected lands, generalized zoning, and land cover. Values greater than 50 are relatively repulsive to growth with 100 being completely excluded. Values less than 50 are relatively attractive to growth (e.g., areas zoned for moderate- or high-density growth). The midpoint, 50, is neutral.

The probability output from SLEUTH is overlaid on a raster land cover data set to determine the relative proportions of land cover classes and sewer areas affected by future growth. For example, if a cell with a 50 percent probability of becoming developed by 2030 overlays a forest cell in the land cover map, 50 percent of that quarter-acre cell is considered forest loss. For each modeling segment, the total acreage of all land cover classes converted to urban growth is summed and divided by the total amount of urban growth acreage forecasted in the modeling segment. That process generates relative proportions of future growth by land cover class for each modeling segment. Multiplying those proportions by the acreage of forecasted growth (generated by GAMe) determines how much acreage of forest, farmland, or infill to subtract or add in future years to the Phase 5 watershed model 2002 baseline land use classes.

This forecasting process was reviewed extensively by state and local government agencies and by the Scientific and Technical Advisory Committee in 2008.

4.7.4 Phase 5.3 Developed Land Cover Forecasts

For the current version of the watershed model, SLEUTH is not being used because of the lack of resources to recalibrate the model using the new CBLCD and because the investment of resources to do so for the Phase 5.3 Chesapeake Bay Watershed Model was unwarranted, given the gross underestimation of low-density residential areas in the CBLCD, which is a characteristic of land cover data sets derived solely from Landsat satellite imagery. In place of SLEUTH, the CBLCD was analyzed in each modeling segment to estimate the proportions of forest or farmland converted to development and infill occurring between 1984 and 2006. Those proportions of conversion and development are assumed to continue through the year 2025.

GAMe, described below, is being used for Phase 5.3 and was updated to include (1) the most recent county-level population projections produced by each state; (2) updates to the Chesapeake Bay Protected Lands Database; (3) consideration of the 2009 population and housing unit estimates produced by the U.S. Census Bureau; (4) recalculation of the relationship between residential lot size and the percent of undeveloped land using the Maryland Department of Planning’s 2007 parcel database; and (5) reapportionment of housing attributes from U.S. Census Block Groups to modeling segments using updated census and more accurate roads data.

GAMe was originally developed in the mid-1990s for the New Jersey Office of State Planning. It was designed to generate municipal-scale forecasts of housing and office space demand that account for the availability of vacant housing, office space, and open land for development, while maintaining consistency with county-scale projections of population and employment. To ensure consistency with county-scale projections, GAMe includes an iterative fitting routine to ensure that the county-scale demand for housing and office space is accommodated within each county even though certain municipalities might not be able to accommodate local demand. At this time, the CBLCM includes only the housing demand and forecast components of GAMe.

GAMe requires exogenous population projections as the basis for forecasting housing demand. For the Bay watershed, county population projections were supplied by state agencies, consultants to state agencies, the Washington Metropolitan Council of Governments, and the Hampton Roads Planning District Commission, out to the years 2010, 2020, and 2030. In counties where projections were provided by multiple organizations, the more locally derived estimates were used. Projections for all future years were scaled on the basis of the ratio of published 2009 housing unit estimates extrapolated to 2010 to the local 2010 projections. The county population projections were converted into housing demand estimates using Equation 1, Figure 4-14. Those estimates were used to constrain forecasted housing estimates at the modeling segment scale.

Equation 1.

$$\text{Total Housing in Year X} = \frac{(\text{Pop. Projection for Year X}) - (\text{Group Quarters Pop. In Year X})}{(\text{Extrapolated Average Household Size in Year X})} + \text{Vacant Housing in Year X}$$

For Virginia and the Washington D.C. metro region, Group Quarters data were provided by Mike Sparr at the University of Virginia and the Washington Metropolitan Council of Governments. In all other jurisdictions, Group Quarters data for future years were linearly extrapolated from the years 2000 to 2009 based on the U.S. Census Bureau's population and housing estimates.

Future vacant housing was set as a constant percentage of vacant to occupied housing in the year 2000 for each county using data from the U.S. Census Bureau.

Average household size was linearly extrapolated to future years by analyzing the trends over the years 1980, 1990, 2000, and 2010 using data from the U.S. Census Bureau.

Figure 4-14. Converting county population to housing demand.

To implement GAMe at the modeling segment scale, U.S. Census data on total housing units must be apportioned from census boundary files to the modeling segments. While Census Block Group boundaries are not the finest scale census boundary, they contain substantially more information on housing attributes compared to Census Block scale; for that reason, Block Group data were used. To apportion the number of total housing units from block groups to segments, a dasymetric mapping technique was implemented using road density information (Claggett and Bisland 2004). The line density of secondary roads identified in NAVTEQ company's 2006 streets data set was computed throughout the Bay watershed using a 500-meter-radius circle focal sum function in a GIS, excluding areas of steep slopes, emergent wetlands, open water, and public/protected lands, and snapping the resultant data set to the 30-meter 2006 CBLCD. The total road density within each Census Block Group was calculated, and the Block Groups were then converted to a raster using the total road density values. Dividing the original road density raster by the Block Group total road density raster resulted in a raster data set showing the proportions of a Block Group's total road density within each 30-meter cell. The Block Groups were then converted into another raster using the total housing unit attribute as the raster value. That raster was then multiplied by the proportion raster to produce a final raster data set with an estimate of total housing units assigned to each 30-meter cell. Adding up all the cell values in a single Block Group would produce the exact number of total housing units reported in that Block Group.

Total housing unit raster data sets were produced using the 1990 and 2000 U.S. Census Bureau Block Group data sets. While using 2005 secondary road density to distribute 1990 and 2000 data does introduce some error, 1990 and 2000 road data sets of comparable quality to the 2006 NAVTEQ data do not exist for the region. The fact that many of the 1990 Census Block Groups in high growth areas were subdivided or re-delineated (or both) in 2000 could reduce the degree of error. The 1990 and 2000 total housing unit raster data sets were aggregated to Chesapeake Bay Watershed Model segments to estimate the number of total housing units present in 1990 and 2000 in each segment.

To forecast future housing at the watershed segment scale, GAMe fits Gompertz curves computed with an exponential growth function limited by an exponential decay constraint (Equation 2, Figure 4-15).

Equation 2.

$$\text{Maximum housing stock} = \text{Current housing stock} + \frac{\text{Available land for residential development (acres)}}{\text{Developed land per house (acres/housing unit)}}$$

Figure 4-15. Forecasting future housing stock.

The Gompertz family of growth curves has been used effectively to simulate housing growth at the sub-county scale (Reilly 1997). Gompertz curves have a shape that makes them especially suitable for modeling situations in which (1) growth is at first slow (such as when an agricultural or forested area is beginning to be developed); (2) growth takes place rapidly (such as when fairly large tracts are being developed into suburban housing subdivisions); and (3) growth trails off but does not come to a frank stop (such as when marginal areas in suburban areas or cities are developed or urban redevelopment entails marginal increases in housing density). The Gompertz curve equation used in the CBLCM is displayed in Equation 3, Figure 4-16. The Gompertz fit curve is illustrated below in Figure 4-17.

Equation 3.

$$y(t) = ae^{be^{ct}}$$

$y(t)$ = housing stock within a particular locality at a point in time t;
a = the asymptotic maxium for $y(t)$ as t approaches infinity;
b = a factor determining or measuring the asymmetry of a curve about the ordinate; and
c = the growth rate.

$a > 0$; $b < 0$; and $c < 0$.

Figure 4-16. Gompertz curve equation.

Additional modeling segment-level data that were needed to fit the Gompertz curve equation were the amount of developed land per housing unit and the amount of undeveloped land eligible for development. Dividing the developed area footprint (as defined using the 2001 CBLCD) by the total number of housing units in 2000 generates a ratio of acres per unit, which is then multiplied by the amount of eligible undeveloped land to estimate the maximum housing unit capacity at current densities in a segment (Equation 2, Figure 4-15).

To forecast growth in housing stock with Gompertz curves, a symmetry assumption was made, which determined the variable b; then maximum housing stock a was identified for each area; next, the growth-rate parameter c was computed from the 1990 and 2000 Total Housing Unit decadal data points; and finally, the proportion p of maximum possible housing stock that had already been built in calendar year 2000 to convert calendar years into the independent time variable for the Gompertz curve determined by the parameters *a*, *b*, and *c*.

The Gompertz curves were used to forecast total housing demand in 2010, 2017, and 2025 at the model-segment scale. Those local forecasts were then summarized by county and compared to the county-scale estimates of total housing units derived from the state and local population projections (see Equation 1, Figure 4-14). Differences between the segment- and county-scale estimates of housing demand were used to adjust the segment-scale estimates to conform to the county-scale totals.

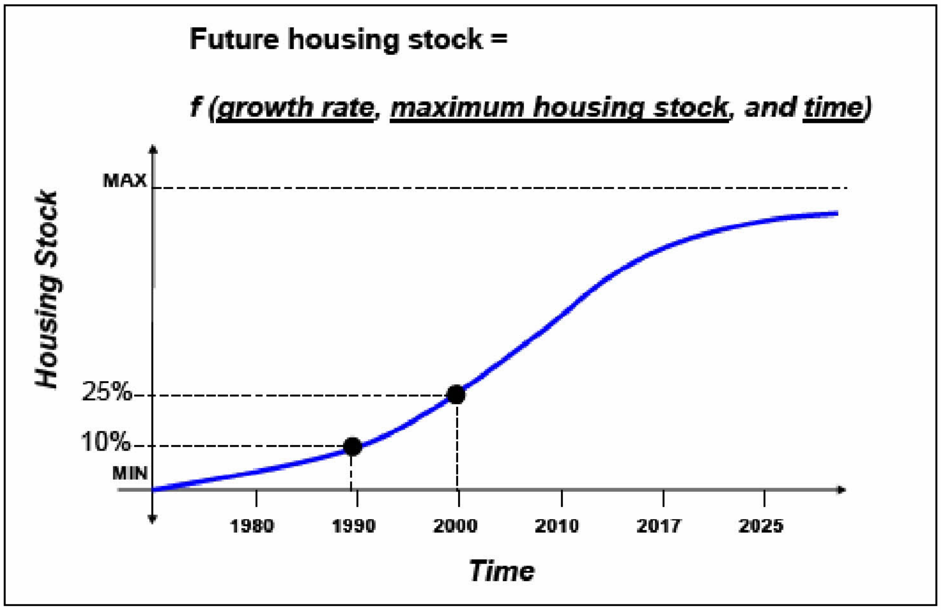


Figure 4-17. An illustration of the Gompertz curve fit.

The initial step in converting future housing demand into urban area was to multiply the area of developed land per housing unit used in Equation 2 by the total number of future households. That value was then adjusted on the basis of the assumption that future housing densities are likely to increase as the percent of undeveloped land decreases. The relationship between residential lot size and undeveloped land was tested at the modeling segment scale by statistically comparing both variables in Maryland (Figure 4-18). Median residential lot size for all modeling segments in Maryland was determined using the 2007 Maryland PropertyView parcel point database. The percentage of non-urban land in each modeling segment was determined by tabulating the areas 2001 CBLCD classes within each modeling segment. The percentage of non-urban land was used in place of the percentage of eligible undeveloped land for residential development because protected lands, a component of undeveloped land, confound the relationship. Large residential lots are often adjacent to public or protected lands in rural areas even though the percent of land available for development in the surrounding modeling segment might be low because of the presence of those public or protected lands. The regression equation displayed in Equation 1, Figure 4-14 was used to estimate the average lot size for the year 2000 and in future years. The ratios of future year lot size estimates to the year 2000 estimates were used as *densification* factors that were multiplied by the amount of urban land per housing unit in the year 2000 to generate adjusted future urban area estimates for each modeling segment. Table 4-13 below provides an example of a modeling segment in Delaware and illustrates how GAMe functions to estimate future housing units and developed land area.

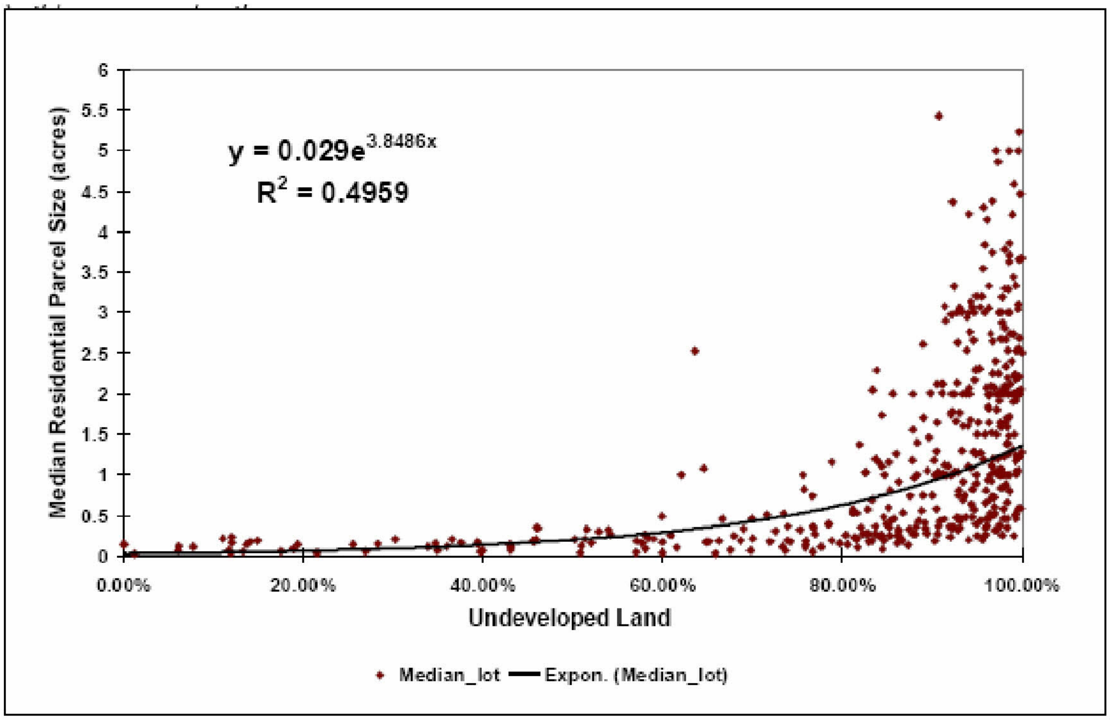


Figure 4-18. Relating median parcel size to the percent of non-urban land within each modeling (e.g., *land-river*) segment.

Table 4-13. GAMe results of a modeling segment in Kent County, Delaware, modeling segment.

Segment #: A10001DEO_3380_0000	
1990 Housing Units:	2,961
2000 Housing Units:	3,500
2000 CBLCD Developed Land (interpolated):	1,698 acres
Ratio of Developed land to Housing units:	0.49 acres per unit
Undeveloped land eligible for growth:	13,626
Maximum number of housing units possible:	31,584
2010 Housing unit estimate:	4,089
2017 Housing unit estimate:	4,529
2025 Housing unit estimate:	5,059
Ratios of housing unit estimates at county scale to county population projections:	
2010 ratio	1.11
2017 ratio	1.08
2025 ratio	1.02
Housing unit estimates adjusted with above ratios:	
2010 Housing unit adjusted estimate:	4,533
2017 Housing unit adjusted estimate:	4,898
2025 Housing unit adjusted estimate:	5,177
Translation of housing units into developed land using 0.47 acres per unit ratio:	
2010 Developed land estimate:	2,199 acres
2017 Developed land estimate:	2,376 acres
2025 Developed land estimate:	2,512 acres
Revised developed land estimates accounting for densification:	
2010 revised estimate (* 0.90):	2,150 acres
2017 revised estimate (* 0.87):	2,304 acres
2025 revised estimate (* 0.85):	2,419 acres

4.7.5 Phase 5.3 Sewer and Septic Forecasts

The CBLCM also includes a Sewer Model to estimate the population on sewer and septic and the number of on-site septic systems in the years 2010, 2017, and 2025. The critical data set for estimating these variables is a polygon representation of current and future sewer service areas.

In the fall of 2009, EPA contracted with Tetra Tech to contact the 403 major wastewater treatment plants (WWTPs) in the Bay watershed and request digital maps of their current and future service areas. Approximately 257 WWTP facilities submitted data in one form or another (e.g., hard copy data, ESRI shapefiles, PDF files, JPEG files, KML files). The Maryland Department of Planning for all of Maryland, Fairfax County, and the Washington Council of Governments also provided spatial polygon data representing current and future sewer service areas. In 2008 the Chesapeake Bay Program Office contacted local jurisdictions and collected sewer service area data for three counties in Delaware; Albemarle, Arlington, Henrico, Loudoun, and Rockingham counties in Virginia; and James City, Newport News City, Virginia Beach, and Richmond City in Virginia. Data were also collected for Perry, Dauphin, Lancaster, Lycoming, and Cumberland counties in Pennsylvania and for Broome County in New York.

In areas where data were not provided by a state or local government or from a WWTP, the Chesapeake Bay Program Office simulated the extent of existing sewer service areas using a thresholded and log-transformed raster data set of year 2000 population density (produced using similar methods as were used to rasterize the housing unit data). The logarithmic transformation was used to normalize the population density data in the surface raster. The standard deviations in the data range were examined to find the optimal threshold for representing sewer service areas in Maryland. A threshold of 1.5 standard deviations from the mean (> –0.4177) was chosen and used to reclassify the surface raster into a binary grid. A low pass filter (ignoring no data) was then used to smooth the data, and the output was converted from a floating point to an integer grid. The resulting integer grid was used to represent potential sewer service areas and serve as a mask for summarizing the original population surface data by county. Compared to Maryland's mapped residential sewered areas, this modeling approach captured 81 percent of Maryland's mapped residential sewered areas according to a one-to-one pixel comparison. The user's accuracy was only 58 percent because the modeling approach generates more sewered areas than actually exist. That is a very conservative estimate of user's accuracy, however, because it is likely that sewer service has expanded since the 2000 Census. Moreover, this modeling approach is based on the assumption that areas with high residential population densities are likely to have sewer service. Errors of commission (e.g., high- and moderate-density residential neighborhoods on septic systems) are logical candidates for future public sewer connections. This modeling approach was used to generate sewer service areas for all watershed modeling segments in the Chesapeake Bay watershed. Areas not identified as sewer service areas are assumed to be either undevelopable or served by septic systems.

The approach was also tested in Virginia. Draper Aden Associates (DAA) compiled the 2001, 2003, and 2005 Annual Virginia Water and Wastewater Rate Report, which is a voluntary survey of water and wastewater treatment providers. From those reports, data on residential wastewater units (households on sewer) were extracted for 67 of the 101 jurisdictions covered in the CBLCM. Of the 67 jurisdictions, 10 were among those that provided the Chesapeake Bay Program Office with digital GIS files of sewer service areas representing the actual extent of sewer service areas in 2000. For those 10 jurisdictions, the population surface raster for the year 2000 was summarized within both the modeled and actual sewer service areas, converted to household estimates, and compared to the DAA survey results (Figure 4-19). The strong correlation among the DAA data and the Maryland data with Chesapeake Bay Program Office simulation provide support for the use of spatially explicit representations of sewer service areas based on spatially distributed population surfaces for estimating populations and households on sewer versus septic outside Maryland.

For 18 WWTPs that did not respond to Tetra Tech's survey, the population was not dense enough for USGS to detect the extent of the service area using census and road data. For those facilities, Tetra Tech buffered the point locations of the WWTP by 5 kilometers to represent the potential extent of the service areas.

Of the WWTPs surveyed, 199 also provided maps of future sewer service areas and the MDP provided maps of future sewer service areas for all Maryland counties. For assessing the extent of sewer service areas in the year 2025 in counties where local data were not available, the Maryland sewer service area maps were again used as *ground truth* data. The Maryland Department of Planning has categorized and mapped future sewer service areas into five classes (S2 through S6). The classes roughly correspond to the time frame for construction (e.g., 7 to 20 years) and the stage of planning (e.g., intended, planned, or programmed for service). All the mapped future service areas are anticipated to be constructed in the next 20 years. For that reason, the combined extent of all mapped areas with service categories S2 through S6 was considered representative of the future extent of sewer service in the year 2025. The modeled extent of sewer service areas in the year 2000 was used as a base for spatially expanding the sewer service areas along the existing road network under the assumption that sewer networks usually follow transportation rights-of-way. Roads were coded with a relative travel time according to their road class (Table 4-14) with the assumption that primary and secondary roads sometimes serve as sewer routes for connecting dispersed residential subdivisions. Off-road areas were given a travel speed of 5 miles per hour because new developments on new roads in close proximity of existing sewer lines are likely to be connected to those lines. To expand the roads, a cost distance function was used where costs were represented by travel time and sources were represented by sewer service areas in the year 2000. The resulting cost surface data set was log transformed and the first of six *natural breaks* applied using Jenks algorithm (Jenks and Caspall 1971) served as the threshold for establishing the maximum extent of sewer service areas in the year 2030 for localities that did not provide local information on future service areas. That threshold was chosen by visually comparing the modeled 2025 sewer service areas with information provided by Maryland and local jurisdictions.

Population change in sewer service areas was determined by converting the adjusted watershed segment housing demand estimates to estimates of population. Changes in population were then attributed to the sewer service areas by overlaying the SLEUTH probability raster surface over the sewer service areas and calculating the proportions of forecasted growth within and outside sewer service areas for the year 2030. Those proportions were kept constant for all interim year forecasts between 2000 and 2030.

Table 4-14. Travel time designations used for extending sewer service areas.

CFCC	Description	MPH	TTIME (minutes per meter * 100K)
A1	Primary highway with limited access (e.g., Interstate highways)	65	57
A2	Primary road without limited access (mainly U.S. Highways)	55	68
A3	Secondary and connecting roads (e.g., state and county highways)	40	93
A4	Local, neighborhood, and rural roads	30	124
A6	Road with special characteristics (ramps, traffic circles, etc.)	15	249
Other	A5xs and A7xs (off-road trails, driveways, alleys, etc.)	5	746

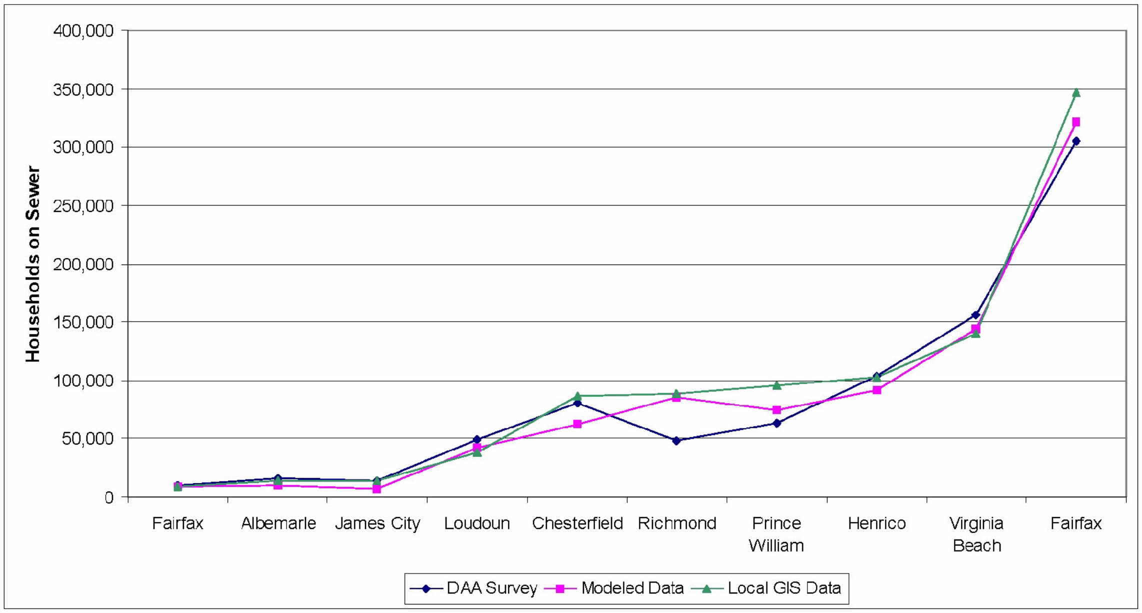


Figure 4-19. Comparison of DAA survey data of households on sewer with a summary of households within locally mapped sewer service areas using a raster surface of households.

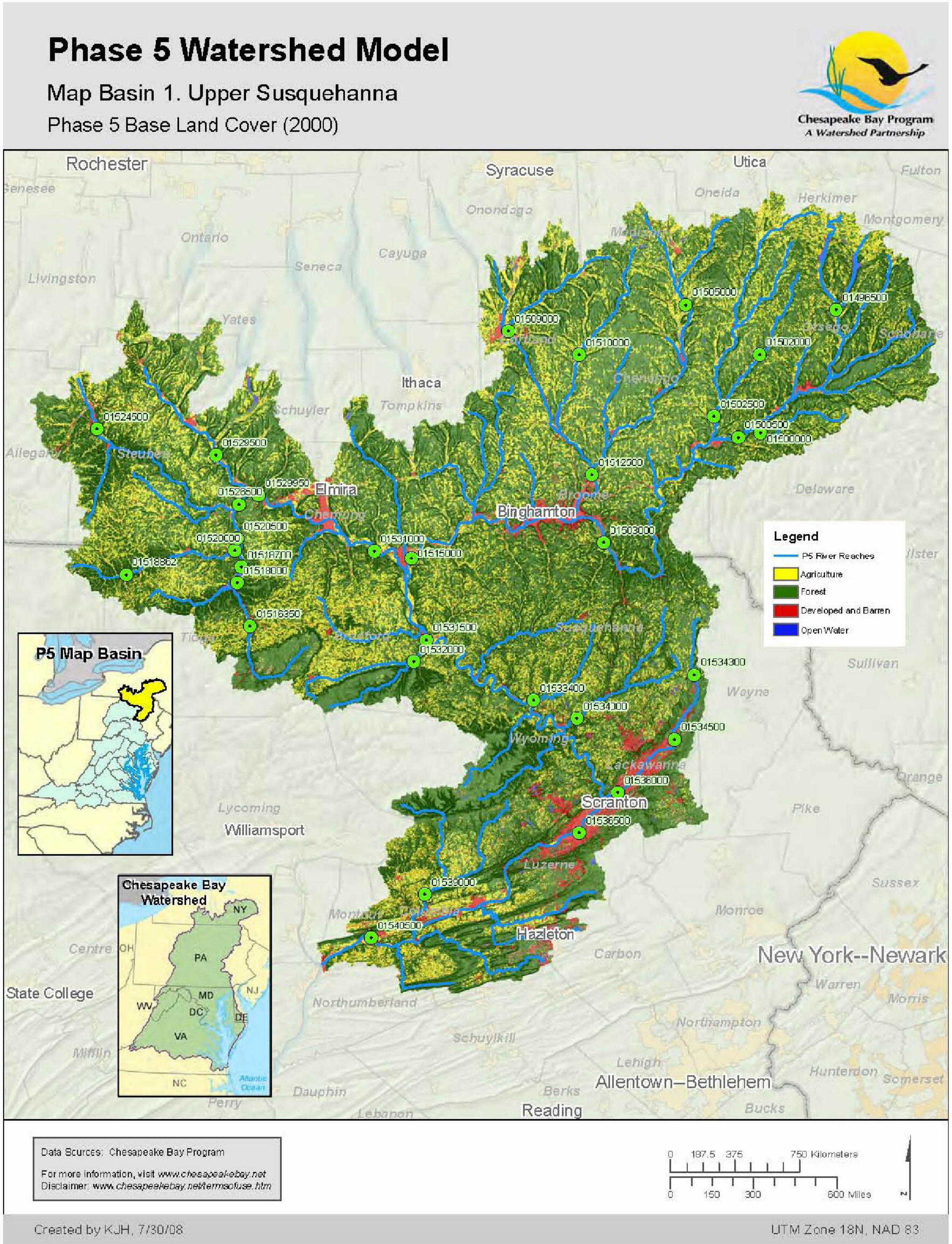


Figure 4-20. Upper Susquehanna River watershed showing Phase 5.3 base land cover.

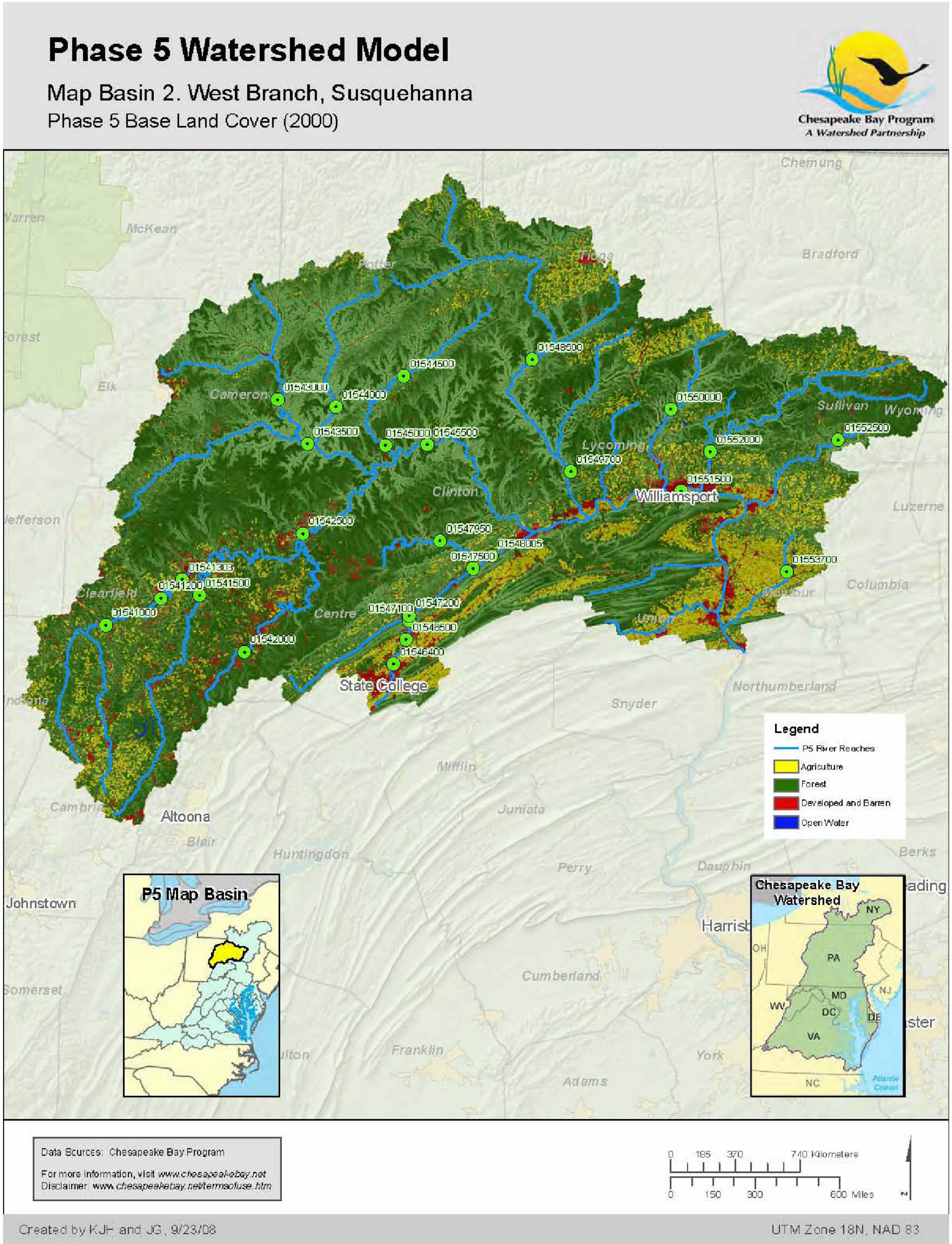


Figure 4-21. Susquehanna, West Branch River watershed showing Phase 5.3 base land cover.

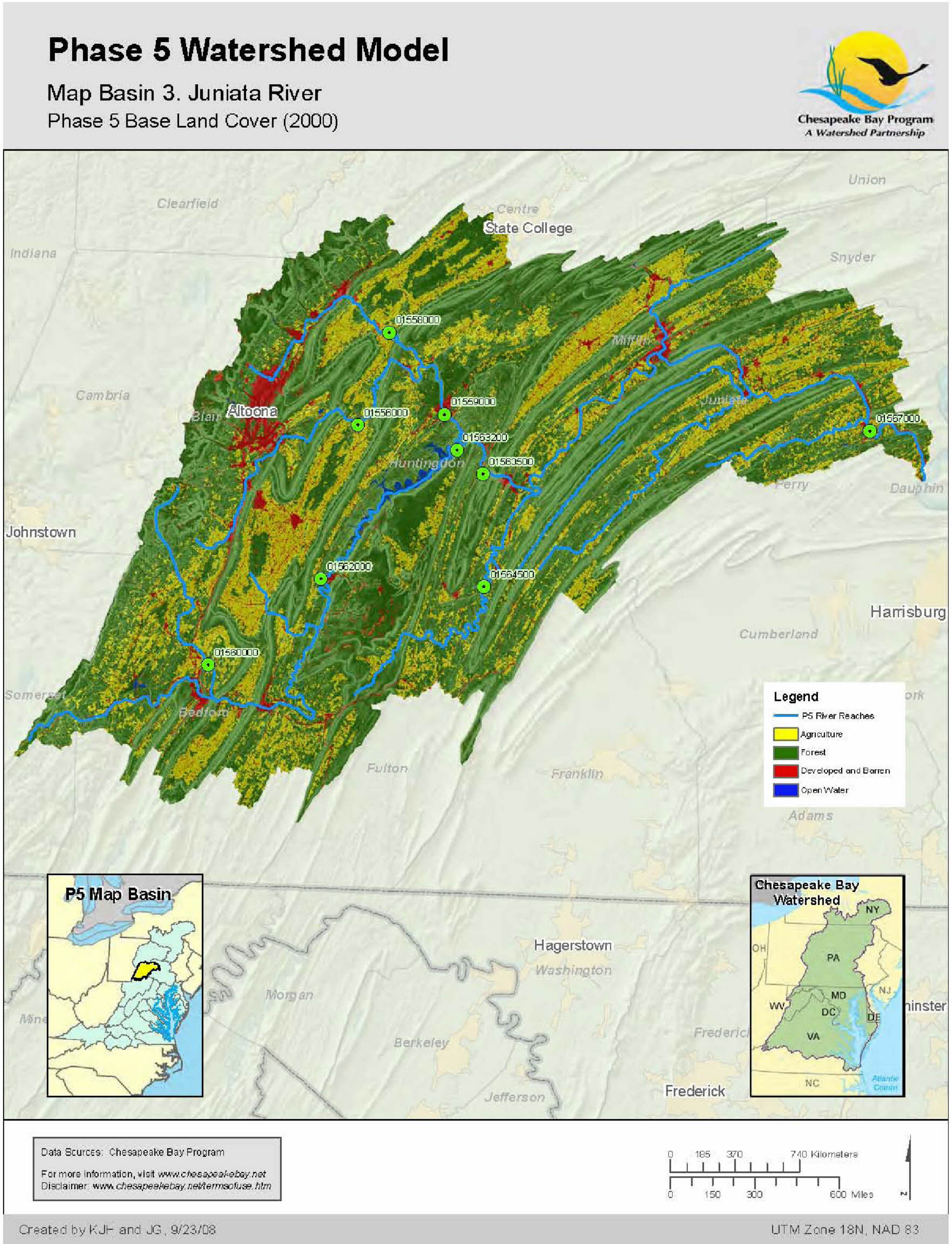


Figure 4-22. Juniata River watershed showing Phase 5.3 base land cover.

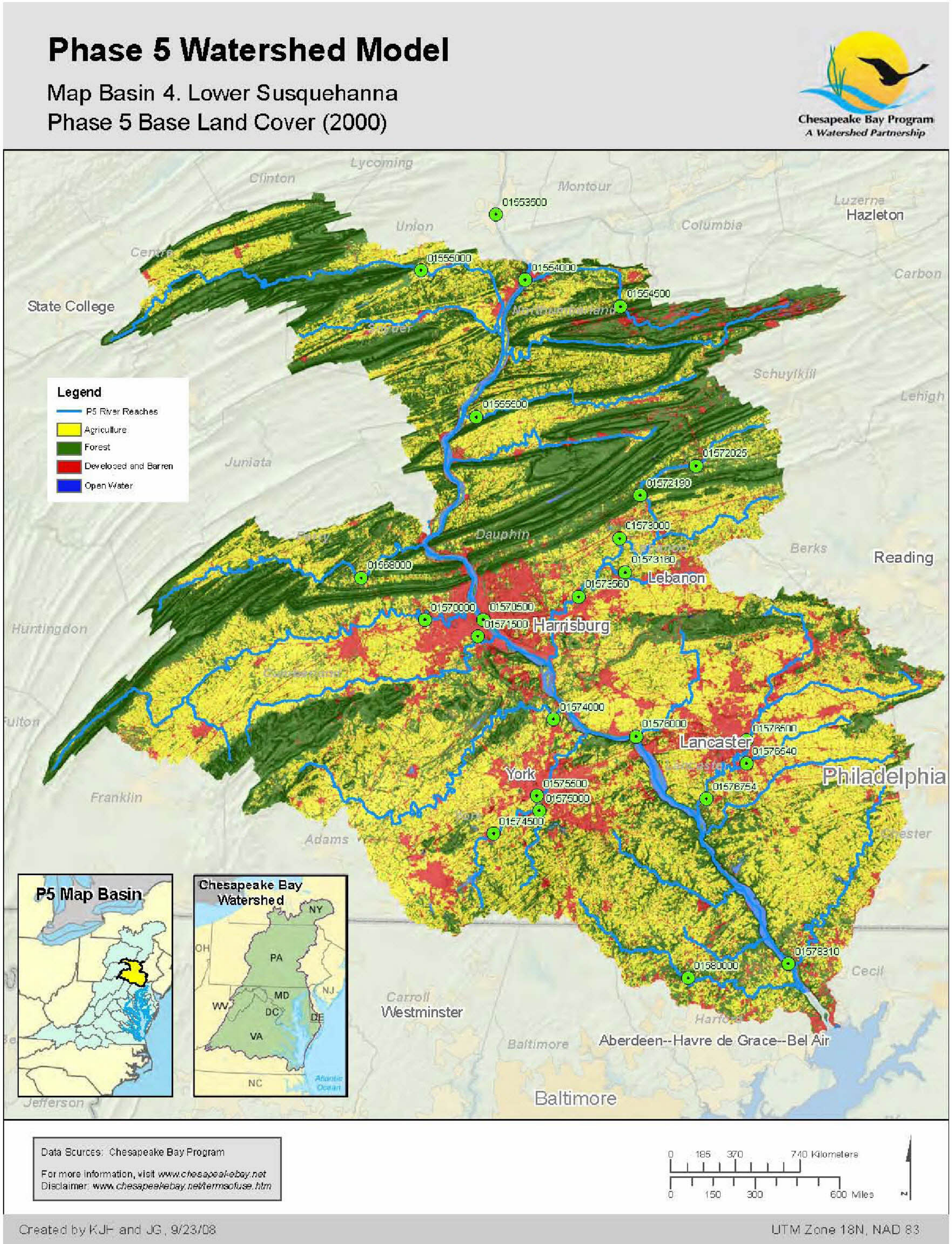


Figure 4-23. Lower Susquehanna River watershed showing Phase 5.3 base land cover.

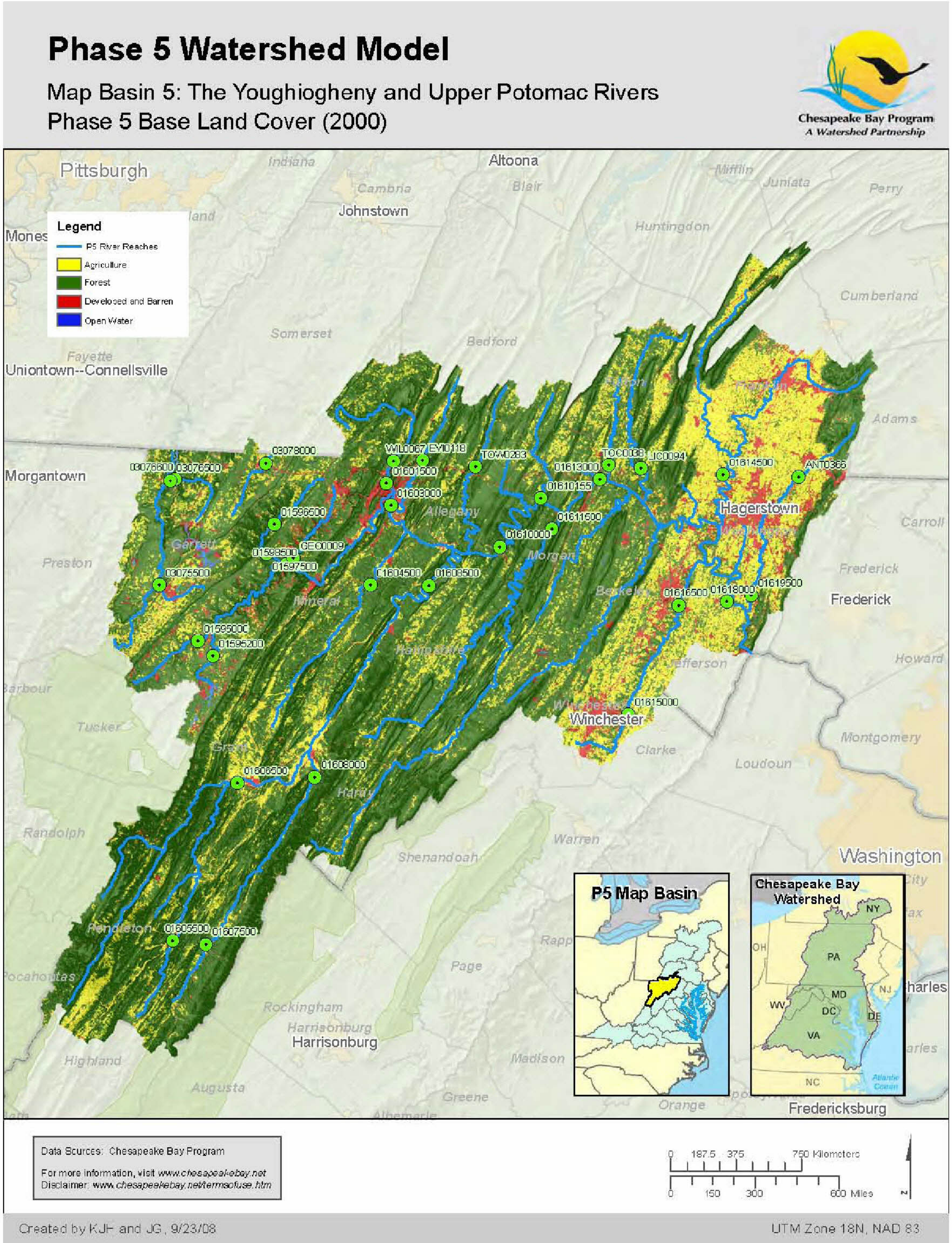


Figure 4-24. Youghiogheny River and Upper Potomac River watersheds showing Phase 5.3 base land cover.

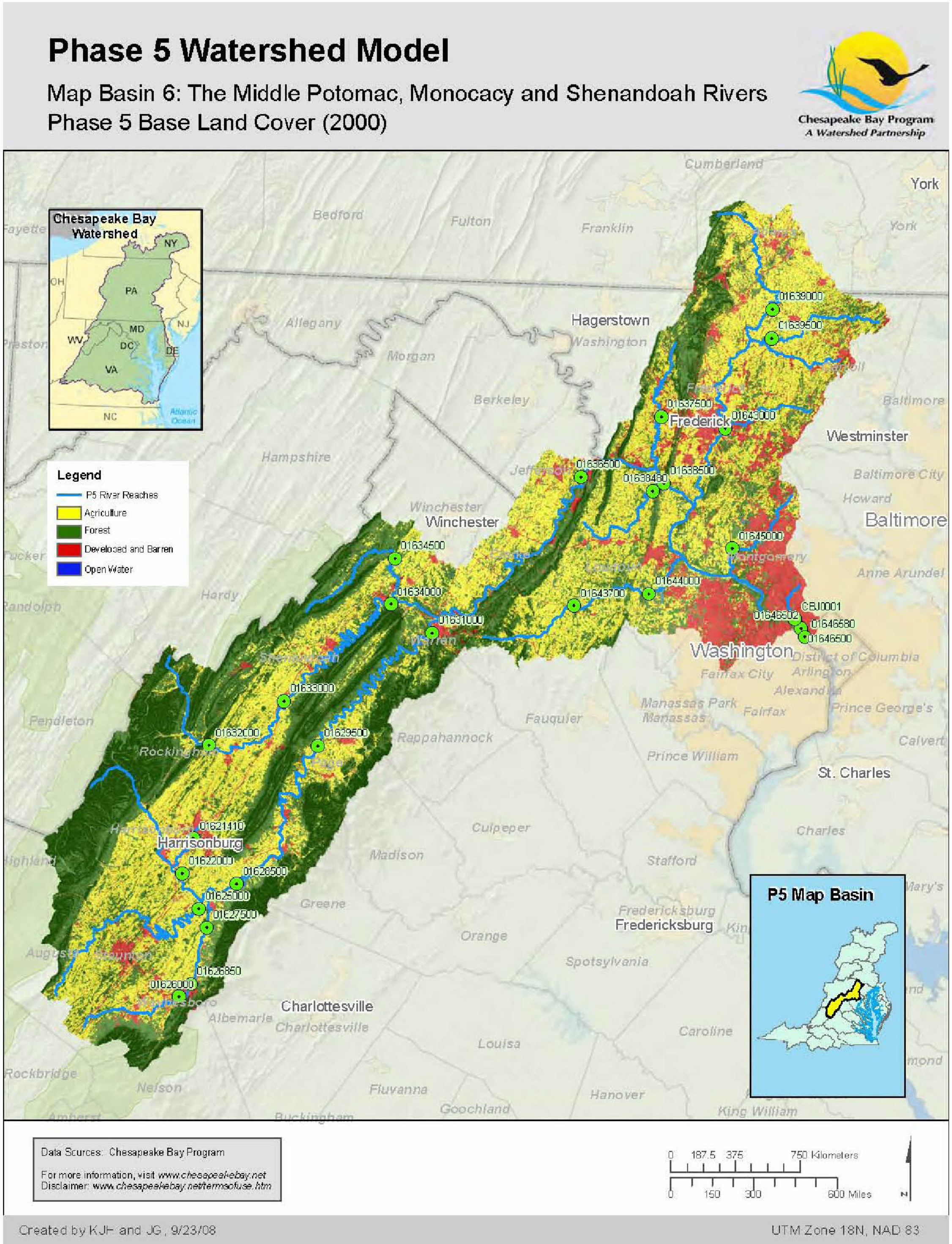


Figure 4-25. Middle Potomac, Monocacy, and Shenandoah River watersheds showing Phase 5.3 base land cover.

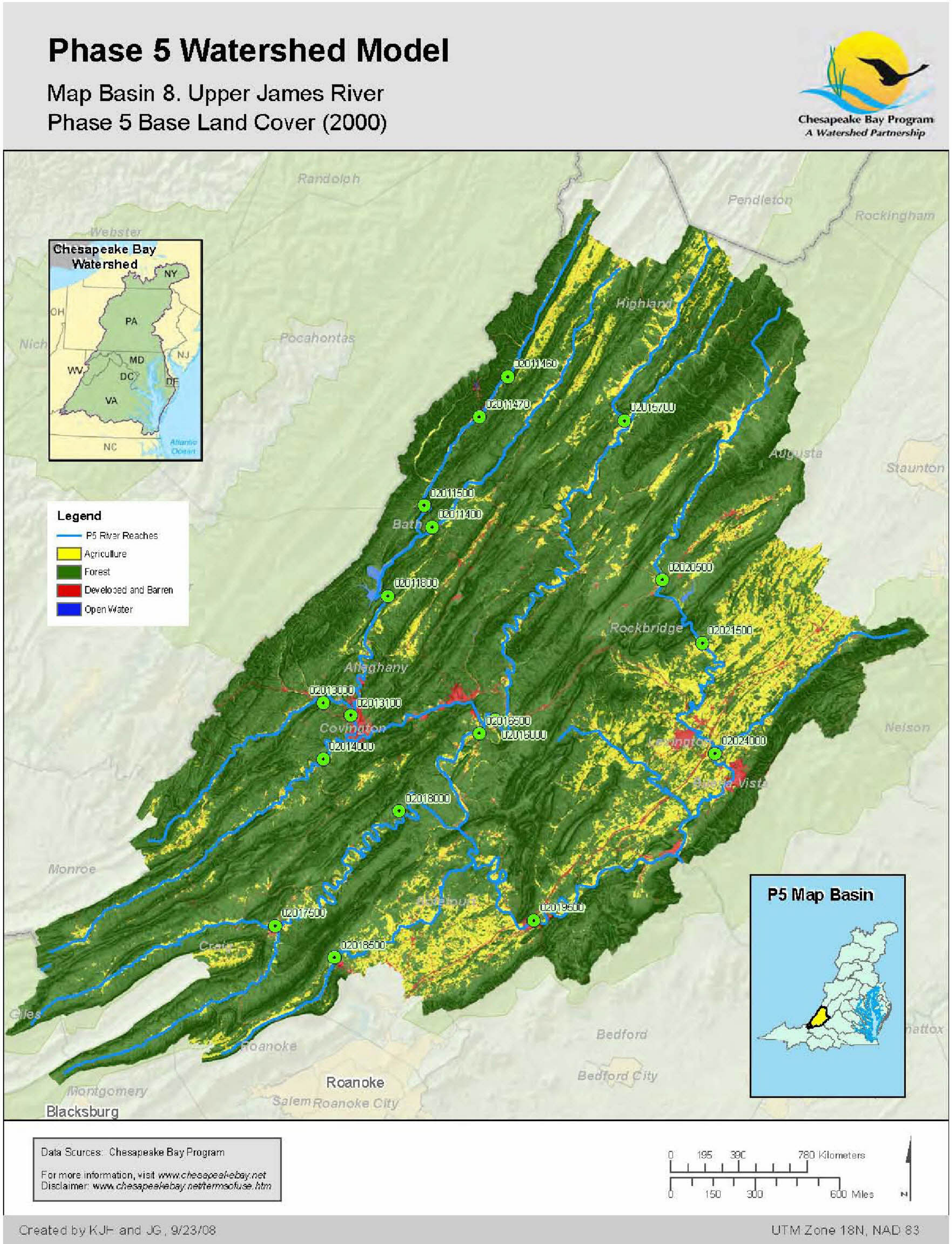


Figure 4-26. Upper James River watershed showing Phase 5.3 base land cover.

AR0014391

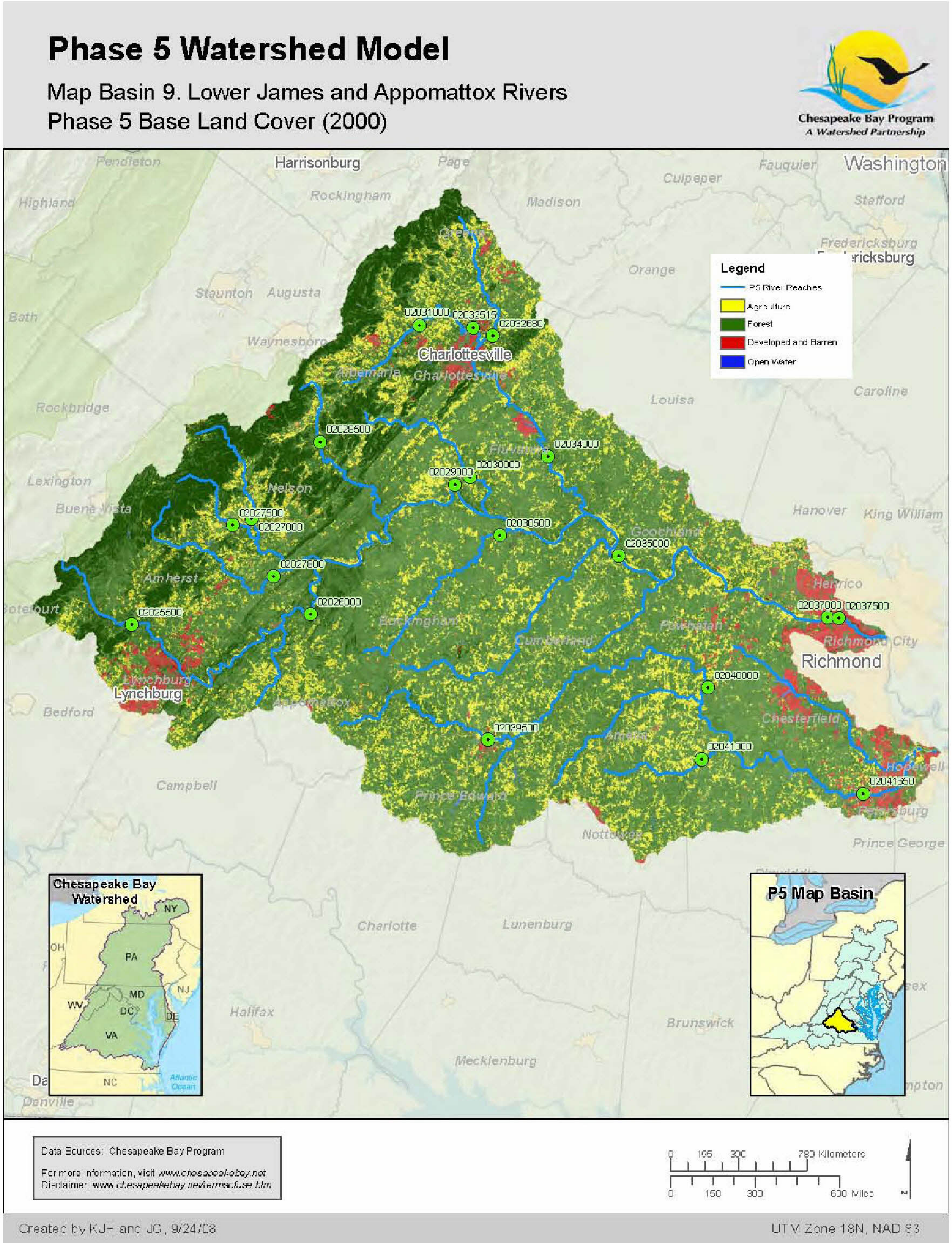


Figure 4-27. Lower James and Appomattox River watersheds showing Phase 5.3 base land cover.

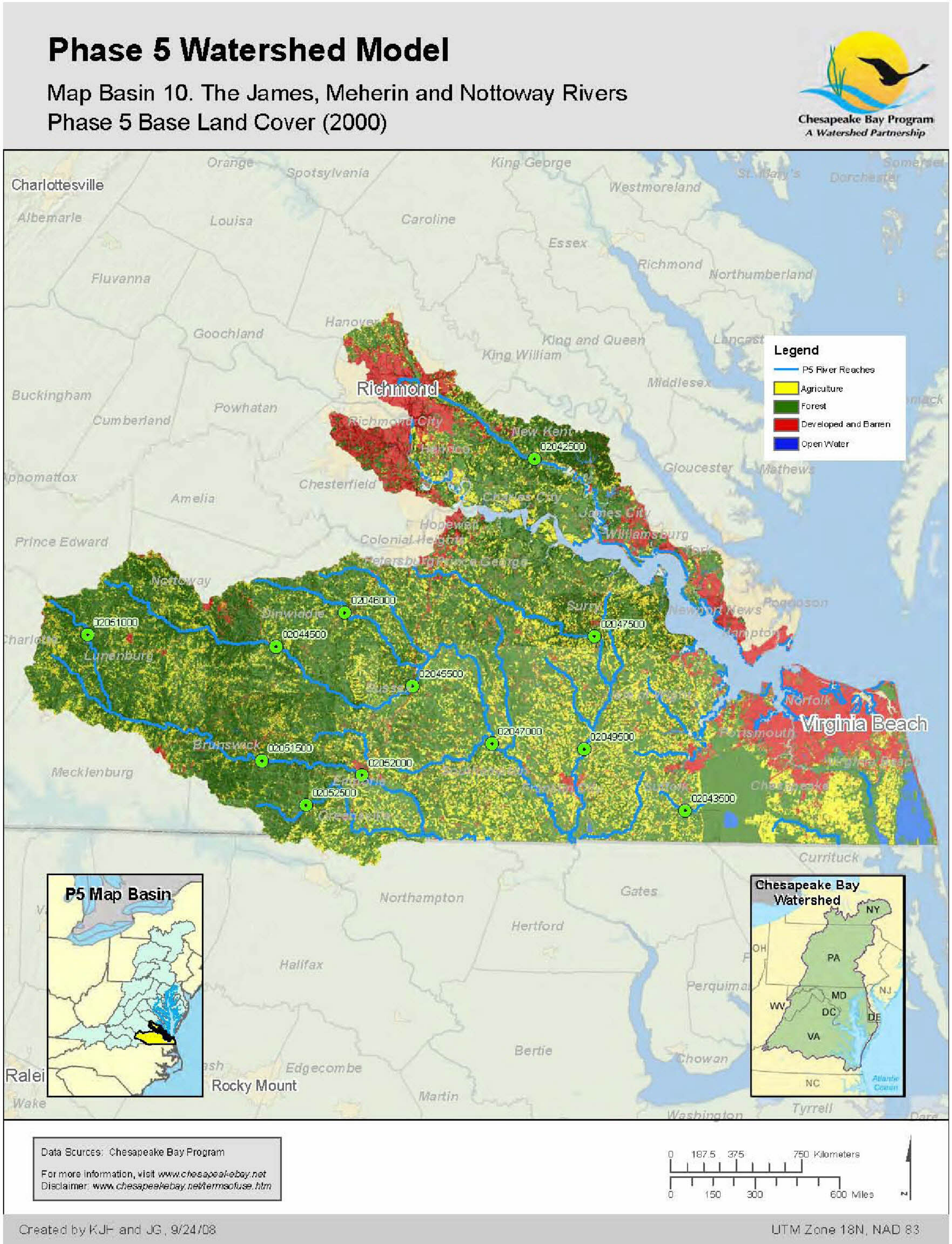


Figure 4-28. James, Meherin, and Nottoway River watersheds showing Phase 5.3 base land cover.

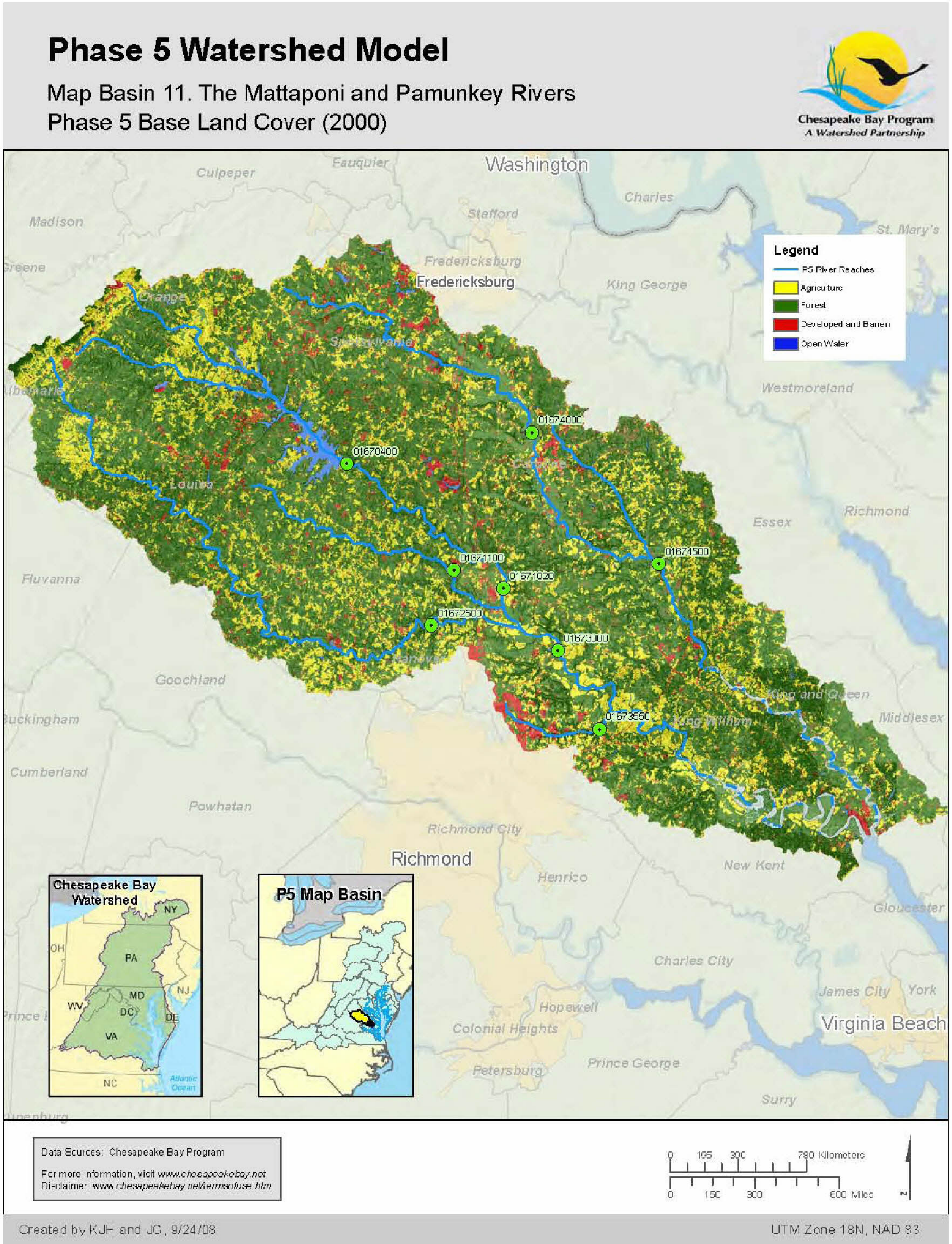


Figure 4-29. Mattaponi and Pamunkey River watersheds showing Phase 5.3 base land cover.

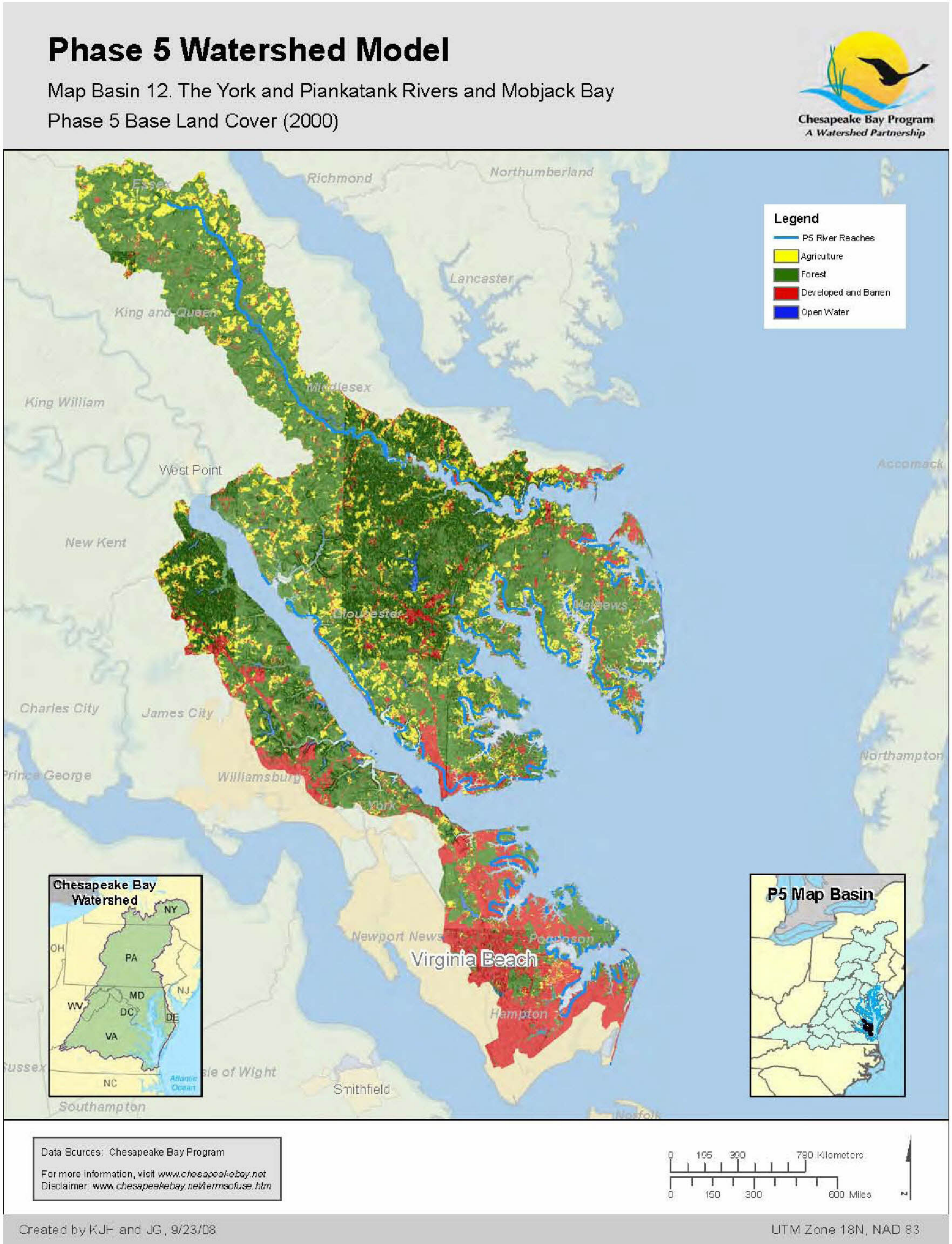


Figure 4-30. York and Piankatank River watersheds and Mobjack Bay watershed showing Phase 5.3 base land cover.

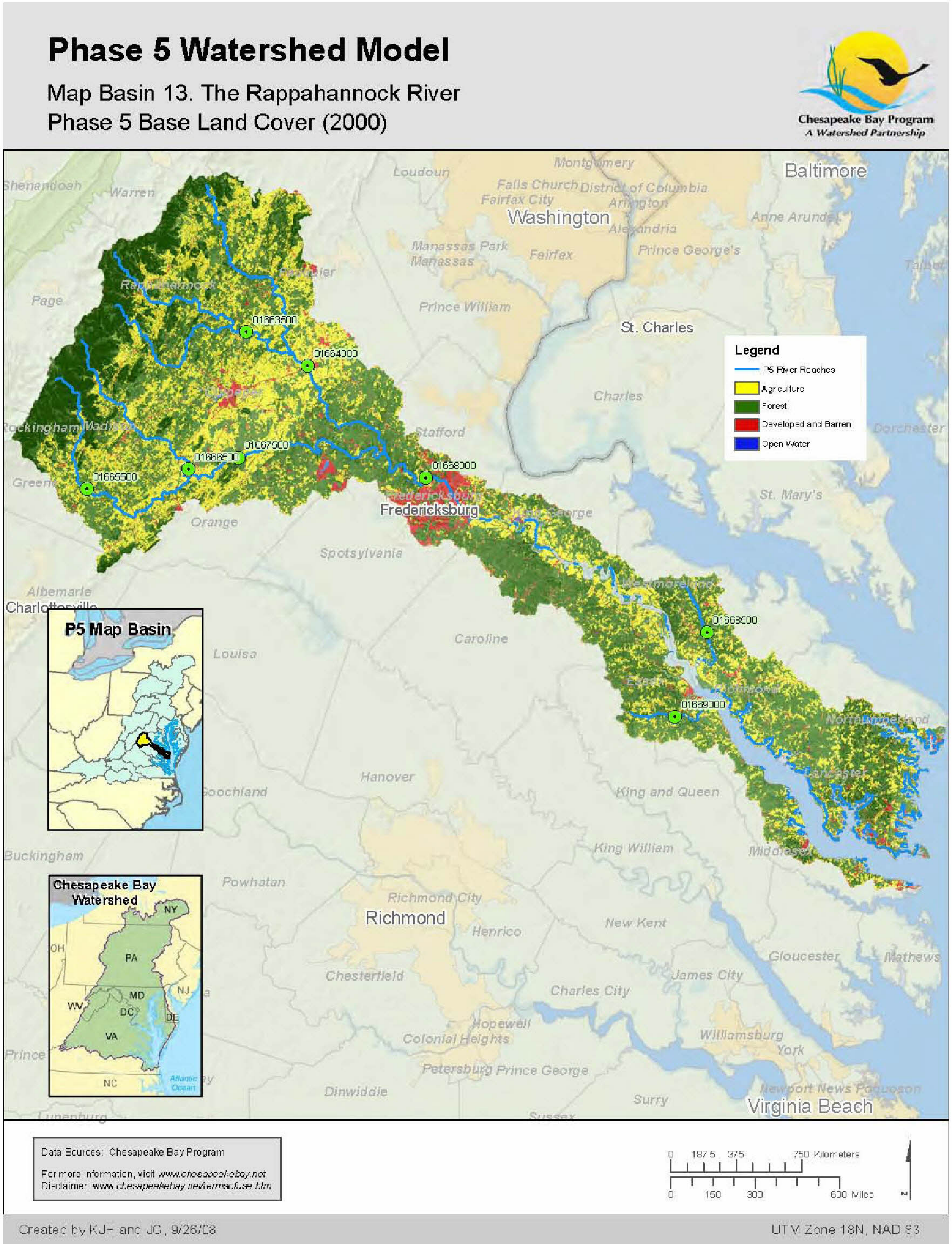


Figure 4-31. Rappahannock River watershed showing Phase 5.3 base land cover.

AR0014396

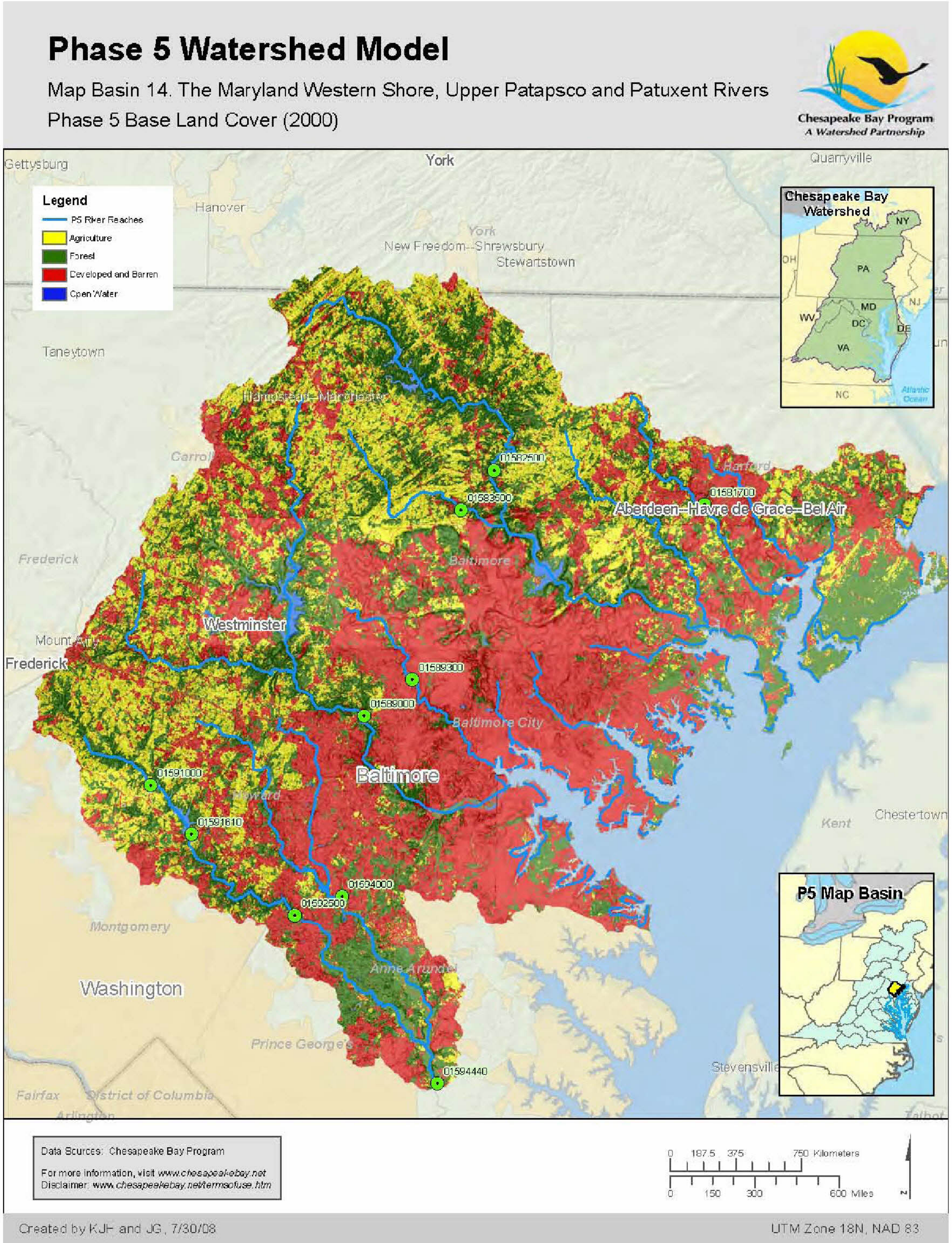


Figure 4-32. Maryland Western Shore, Upper Patapsco, and Patuxent River watersheds showing Phase 5.3 base land cover.

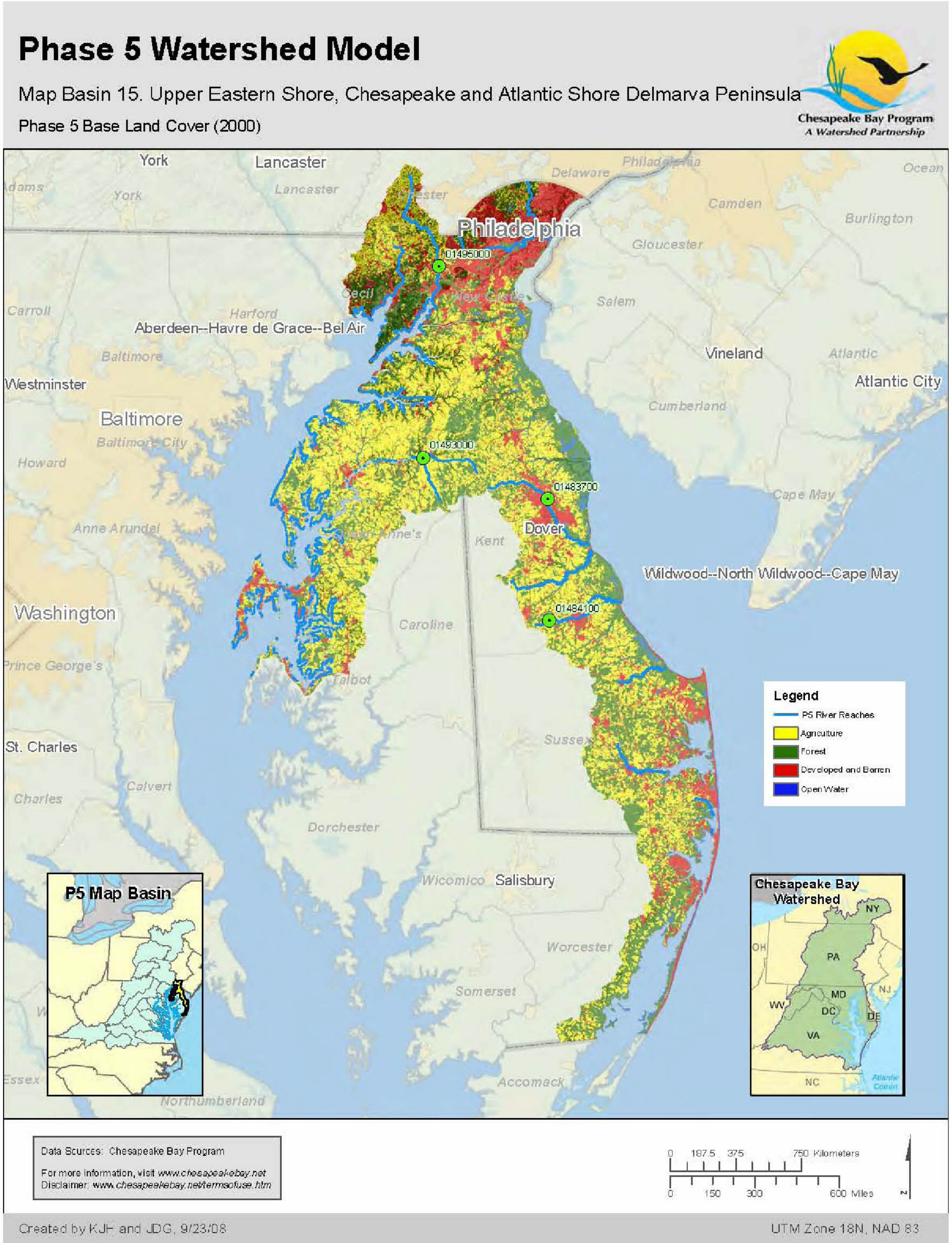


Figure 4-33. Upper Eastern Shore, Chesapeake, and Atlantic Shore Delmarva watersheds showing Phase 5.3 base land cover.

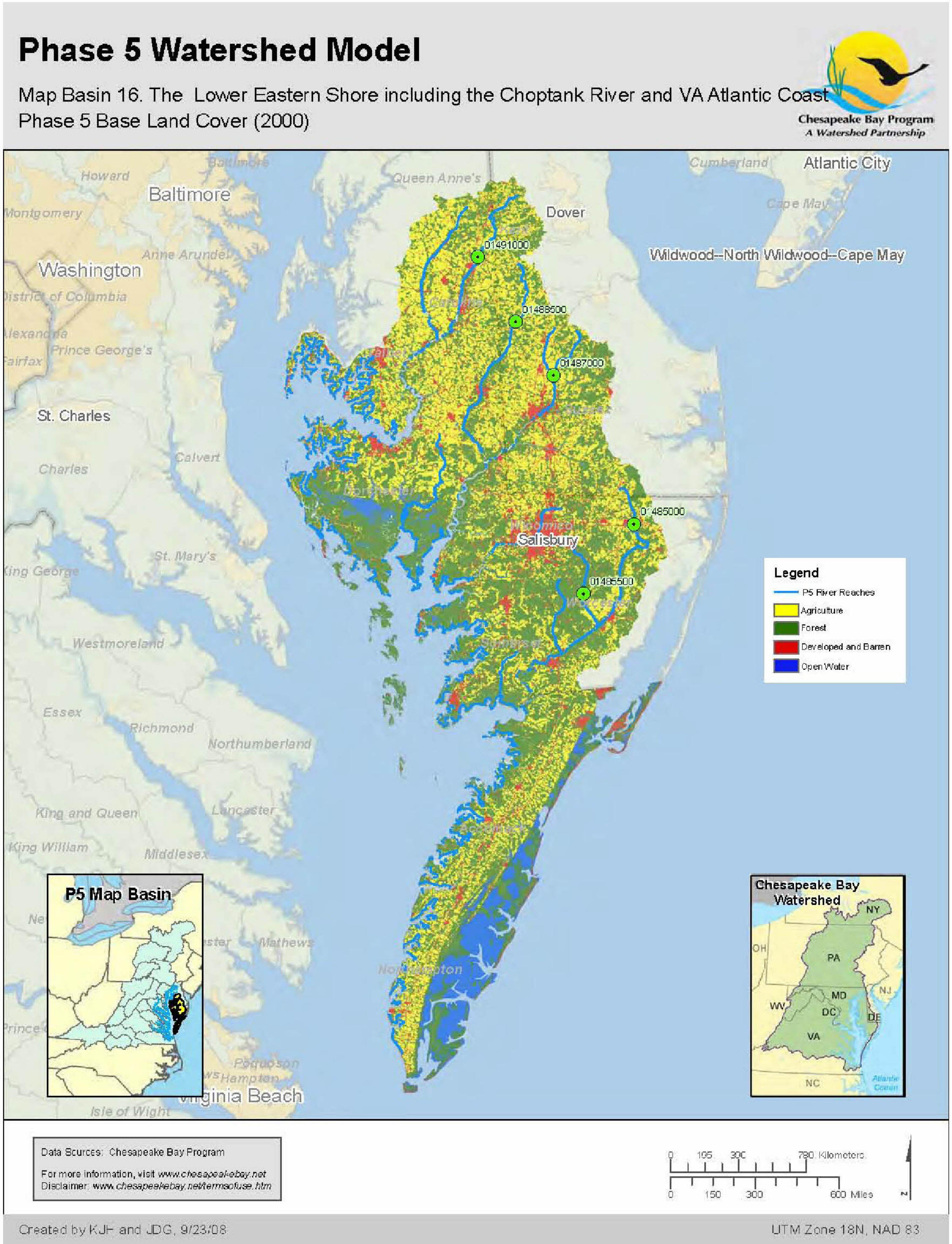


Figure 4-34. Choptank, Lower Eastern Shore, and VA Atlantic Coast watersheds showing Phase 5.3 base land cover.

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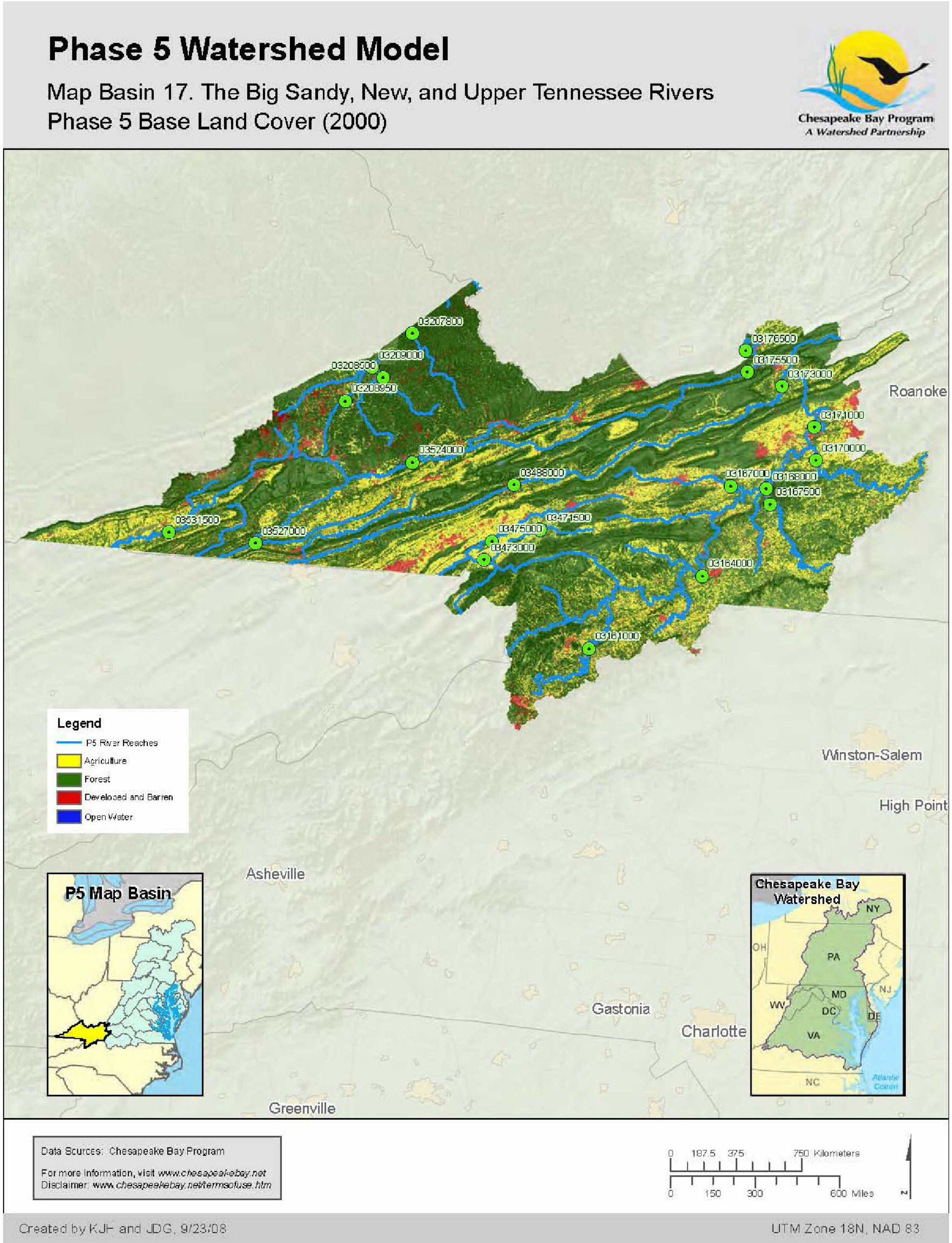

Figure 4-35. Big Sandy, New, and Upper Tennessee River watersheds showing Phase 5.3 base land cover.

AR0014400

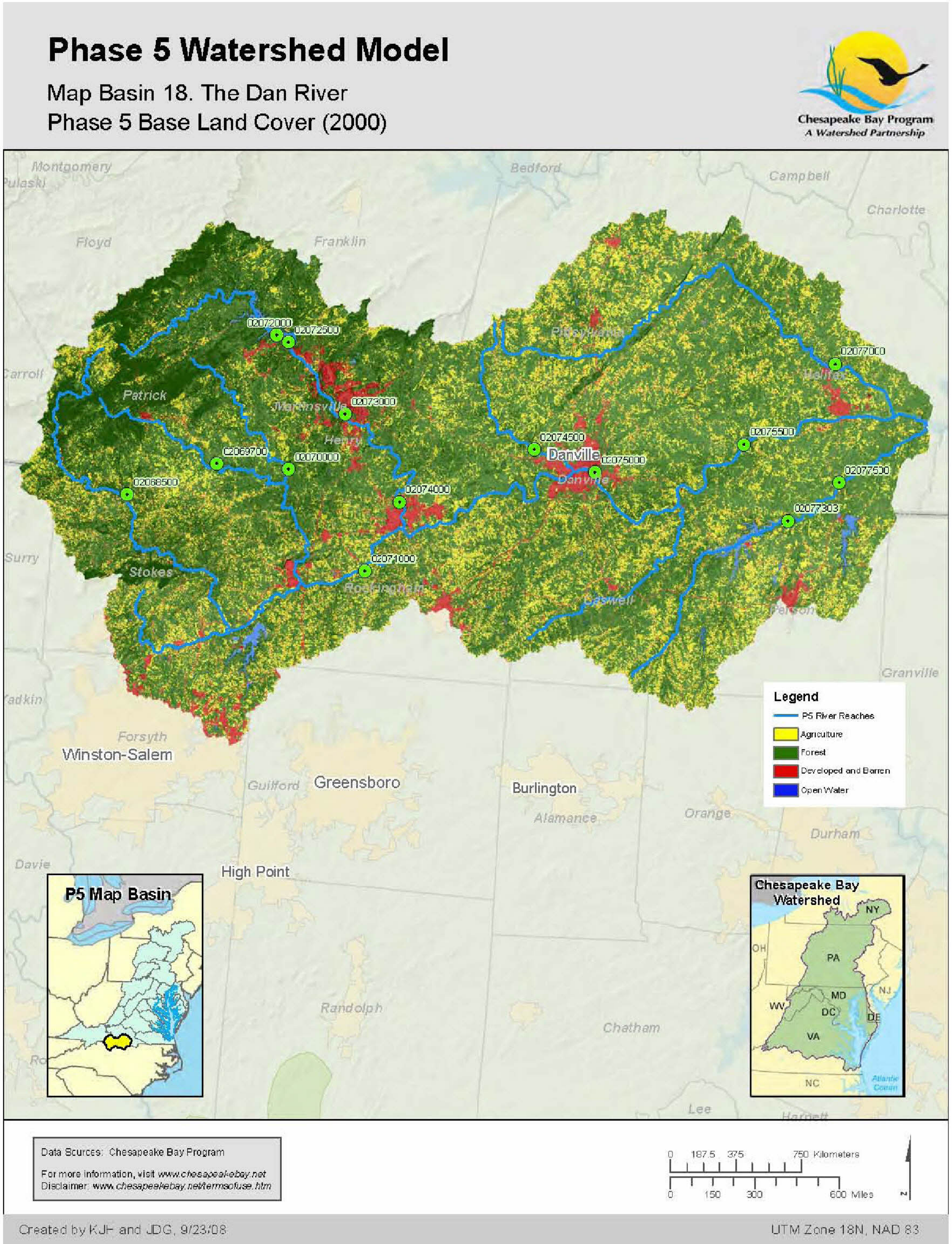

Figure 4-36. Dan River watershed showing Phase 5.3 base land cover.

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